

# RAMP METERING DESIGN MANUAL



California Department of Transportation  
Division of Traffic Operations

April 2016

# **RAMP METERING DESIGN MANUAL**

Prepared by:

California Department of Transportation  
Divisions of Traffic Operations and Design

in collaboration with

the California Highway Patrol

April 2016



California Department of Transportation  
1120 N Street  
Sacramento, CA 95814

[www.dot.ca.gov](http://www.dot.ca.gov)

This manual supersedes all previous versions of the Ramp Metering Design Manual.

This page is intentionally left blank.

## FOREWORD

The California Department of Transportation (Caltrans) is committed to using ramp metering as an effective traffic management strategy. Ramp metering is an integral part of the Caltrans Transportation Management System Master Plan (February 2004), which outlines strategies to reduce congestion and increase safety on California's State Highway System. Ramp metering is used to maintain an efficient freeway system and protect the investment made in freeways by keeping them operating at or near capacity. Proposed projects within freeway segments that have existing or proposed ramp meters listed in the latest version of the Caltrans Ramp Metering Development Plan (RMDP) shall include provisions for ramp metering. Projects designed for new or existing freeway segments without ramp meters, but experiencing recurring traffic congestion and/or having a high frequency of vehicle collisions may consider adding ramp meters. Caltrans Deputy Directive 35-R1 (Appendix A) contains the statewide policy for ramp metering and delegates responsibilities for implementation. It is the responsibility of the Project Engineer to allow appropriate lead time to include ramp metering in projects.

The Ramp Metering Design Manual (RMDM) was prepared by Caltrans Division of Traffic Operations and Design in collaboration with the California Highway Patrol (CHP). The RMDM is a comprehensive document covering Caltrans' ramp metering policies, design standards, and practices for new or existing ramp meter installations. The RMDM shall be used when planning and designing ramp meters, and is not intended to address operational topics.

The RMDM supplements the *Highway Design Manual (HDM)*, *California Manual on Uniform Traffic Control Devices (CA MUTCD)*, *Caltrans Standard Plans*, *Caltrans Standard Specifications*, *Caltrans Standard Special Provisions*, and other Caltrans design policies. The RMDM is not a textbook or a substitute for engineering knowledge, experience, or judgment. The use of this manual does not create any standard of conduct or duty toward the public. The standards found in this manual are the minimum standards and should not preclude sound engineering judgment based on experience and knowledge of the local conditions. Design variations may be necessary on a location-by-location basis as conditions and experience warrant. However, significant design variations from the RMDM are subject to approval from the Caltrans Headquarters (HQ) Traffic Operations Liaison and Caltrans HQ Project Delivery Coordinator.

## STANDARDS, PROCEDURES, AND POLICIES

The nomenclature used for ramp metering standards and procedural requirements in the RMDM are discussed below. Specific to the RMDM is the nomenclature used for ramp metering policies. The RMDM is also applicable when planning and designing freeway-to-freeway connector meters. Unless noted otherwise, the policies and standards for freeway-to-freeway connector metering are the same as ramp metering, per Caltrans Deputy Directive 35-R1.

### Ramp Metering Design Standards

Ramp metering design standards are contained in both the HDM and RMDM. Designers need to refer to the HDM for all geometric-related design standards that apply to ramp metering. Any deviations from geometric-related design standards need to be approved in accordance with HDM Index 82.2 and the Project Development Procedures Manual (PDPM) Chapter 21. For traffic-related design standards, such as the number of lanes, storage length, and advance warning devices, the Project Engineer needs to refer to the RMDM. Any deviation from the traffic-related standards requires review and concurrence by the Caltrans Deputy District Director of Traffic Operations, Headquarters Traffic Operations Liaison, or the District Traffic Operations Branch responsible for ramp metering as specified in the RMDM. These deviations must be documented in the project file with supporting documentation.

### Procedural Requirements

Procedural requirements are required courses of action to follow and are printed in *italics*.

### Ramp Metering Policies

The ramp metering policies are developed to ensure statewide consistency in ramp metering designs and operations. The policies are indicated using **boxed text** and placed in a separate paragraph for added emphasis. Deviation from these policies requires the preparation of an “Exception(s) to Ramp Metering Policy Fact Sheet” (Appendix B). Concurrence with the proposed deviations from these policies shall be obtained from the Caltrans Headquarters Traffic Operations Liaison or the designated representative as early as possible in the project development process. An Exception(s) to Ramp Metering Policy Fact Sheet requires approval of the Caltrans Deputy District Director of Traffic Operations.

## TABLE OF CONTENTS

Topic	Subject	Page
FOREWORD .....		iii
STANDARDS, PROCEDURES, AND POLICIES .....		iv
<b>CHAPTER 1 - METERED ENTRANCE RAMPS AND CONNECTORS</b>		
1.1	Introduction .....	1
1.2	Number of Metered Entrance Ramp Lanes .....	1
1.3	Lane Width and Shoulder Width .....	2
1.4	Queue Storage Length Design .....	2
1.5	Ramp Metering Deceleration Distance.....	3
1.6	Ramp Metering Acceleration Distance.....	3
1.7	Limit Line Location.....	3
1.8	High Occupancy Vehicle (HOV) Preferential Lanes .....	4
1.9	Converting HOV Preferential Lanes to General Purpose (GP) Lanes..	4
1.10	Enforcement Areas and Maintenance Vehicle Pullouts .....	4
1.11	Metered Freeway-to-Freeway Connectors .....	5
<b>CHAPTER 2 - HARDWARE AND SYSTEM INTEGRATION</b>		
2.1	Introduction .....	12
2.2	Signal Standards and Heads .....	12
2.2.1	Signal Standards .....	12
2.2.2	Signal Heads.....	13
2.2.3	Limit Line Lighting .....	13
2.3	Detectors.....	13
2.3.1	General .....	13
2.3.2	Mainline Detectors .....	13
2.3.3	Entrance Ramp Demand Detectors .....	14
2.3.4	Entrance Ramp Passage Detectors .....	14
2.3.5	Entrance Ramp Queue Detectors .....	14
2.3.6	Count Detectors.....	14
2.3.7	Exit Ramp Detectors .....	14
2.3.8	Detectors at Metered Connectors .....	14

<b>Topic</b>	<b>Subject</b>	<b>Page</b>
2.4	Controller Cabinets.....	15
2.5	Communications.....	15
2.6	Advance Warning Devices .....	16
2.6.1	Advance Warning Devices for Metered Entrance Ramps .....	16
2.6.2	Advance Warning Devices for Metered Freeway-to-Freeway Connectors.....	16
2.7	System Integration.....	17
2.8	Temporary Entrance Ramp Meters.....	17
<b>CHAPTER 3 – SIGNING AND PAVEMENT MARKINGS</b>		
3.1	General Standards.....	31
3.2	Signing.....	31
3.2.1	Vehicle(s) per Green Signs.....	31
3.2.2	Stop Here on Red Signs.....	31
3.2.3	HOV Preferential Lane Signs .....	32
3.2.4	Movement Prohibition and Lane Control Signs .....	33
3.2.5	Advance Warning Signs .....	33
3.2.6	Lane Ends Warning Signs .....	33
3.2.7	Activated Blank-Out Signs.....	33
3.3	Pavement Markings .....	34
3.3.1	General .....	34
3.3.2	Type I Arrow .....	34
3.3.3	Limit Line.....	34
3.3.4	HOV Preferential Lane Symbols.....	34
3.3.5	Edge Lines and Lane Lines .....	34
3.3.6	Pavement Markings at the Lane-Drop Transition Zone .....	34
ACRONYMS .....		44
GLOSSARY .....		45
REFERENCES .....		52
APPENDIX A: Deputy Directive No. 35 R-1 .....		53
APPENDIX B: Sample – Exception(s) to Ramp Metering Policy Fact Sheet .....		57
APPENDIX C: Ramp Metering Design Checklist .....		59
APPENDIX D: Instructions for Using Arrival Discharge Chart.....		61

## LIST OF FIGURES

Figure	Subject	Page
<b>CHAPTER 1 - METERED ENTRANCE RAMPS AND CONNECTORS</b>		
1-1	Typical 2-Lane Metered Freeway Loop Entrance Ramp	6
1-2	Typical 2-Lane Metered Successive Freeway Entrance Ramps (1 GP Lane + 1 HOV Preferential Lane) .....	7
1-3	Typical 3-Lane Metered Freeway Diagonal Entrance Ramp (2 GP Lanes + 1 HOV Preferential Lane) .....	8
1-4	Typical 3-Lane Metered Freeway Loop Entrance Ramp (2 GP Lanes + 1 HOV Preferential Lane) .....	9
1-5	Typical 2-Lane Metered Connector (1 GP Lane + 1 HOV Preferential Lane) .....	10
1-6	Typical 3-Lane Metered Connector (2 GP Lanes + 1 HOV Preferential Lane) .....	11
<b>CHAPTER 2 - HARDWARE AND SYSTEM INTEGRATION</b>		
2-1	Typical Layout of Ramp Metering Elements at an L-9 Interchange .....	18
2-2	Typical Layout of Ramp Metering Elements at a Full-Cloverleaf Interchange .....	19
2-3	Typical Type 1 Signal Standard Installations .....	20
2-4	Typical Mast Arm Signal Standard Installations .....	21
2-5	Typical Signal Standard Placement Detail at Loop Entrance Ramps....	22
2-6	Typical Signal Standard Placement Detail at Diagonal Entrance Ramps .....	23
2-7	Typical Detector Layout for Freeway Mainline .....	24
2-8	Typical Detector Layout for a Two-Lane Entrance Ramp .....	25
2-9	Typical Detector Layout for a Three-Lane Entrance Ramp .....	26
2-10	Typical Detector Layout for an Exit Ramp .....	27
2-11	Typical Detector Layout for a Metered Connector.....	28
2-12	Typical Advance Warning Devices .....	29
2-13	Typical Advance Warning Device Layout for a Metered Connector ....	30

<b>Figure</b>	<b>Subject</b>	<b>Page</b>
<b>CHAPTER 3 - SIGNING AND PAVEMENT MARKINGS</b>		
3-1	Typical Signing and Pavement Marking (2-Lane Entrance Ramp, 1 GP Lanes + 1 HOV Preferential Lane) .....	36
3-2	Typical Signing and Pavement Marking (2-Lane Entrance Ramp with Intersection/HOV Preferential Lane) ....	37
3-3	Typical Signing and Pavement Marking (3-Lane Entrance Ramp, 2 GP Lanes + 1 HOV Preferential Lane) .....	38
3-4	Typical Signing and Pavement Marking (3-Lane Loop Entrance Ramp, 2 GP Lanes + 1 HOV Preferential Lane) .....	39
3-5	Typical Signing and Pavement Marking (3-Lane Loop Entrance Ramp, 2 GP Lanes + 1 HOV Preferential Lane) .....	40
3-6	Typical HOV Preferential Lane Pavement Markings .....	41
3-7	Lane-Drop Transition Zone Pavement Markings (2 GP Lanes + 1 HOV Preferential Lane on the Left Side) .....	42
3-8	Lane-Drop Transition Zone Pavement Markings (2 GP Lanes + 1 HOV Preferential Lane on the Right Side) .....	43

---

## LIST OF TABLES

---

Table	Subject	Page
<b>CHAPTER 1 - METERED ENTRANCE RAMPS AND CONNECTORS</b>		
1-1	Minimum Number and Type of Entrance Ramp Lanes (for a typical one vehicle per green operation) .....	2
<b>CHAPTER 3 - SIGNING AND PAVEMENT MARKINGS</b>		
3-1	Regulatory Signs .....	31
3-2	HOV Regulatory Signs .....	32
3-3	Warning Signs .....	33
3-4	Activated Blank-out Signs .....	33

## LIST OF RAMP METERING POLICIES

Topic	Subject	Page
<b>CHAPTER 1 - METERED ENTRANCE RAMPS AND CONNECTORS</b>		
1.2	HOV preferential lanes shall be provided wherever ramp meters are installed, and each HOV preferential lane should be metered. ....	1
1.10	A paved enforcement area shall be incorporated into the design of all projects that include new or reconstructed metered entrance ramps or connectors. ....	4
1.10	A paved maintenance vehicle pullout (MVP) shall be incorporated into the design of all projects that include new or reconstructed metered entrance ramps or connectors. ....	5
1.10	When a freeway-to-freeway connector is metered, an HOV preferential lane shall be provided, and the HOV preferential lane shall be metered. ....	5
<b>CHAPTER 2 - HARDWARE AND SYSTEM INTEGRATION</b>		
2.6	Advance warning devices shall be installed at metered entrance ramps and connectors to alert approaching motorists when ramp meters are in operation. ....	16
2.6.2	On metered freeway-to-freeway connectors, high visibility activated blank-out (ABO) signs shall be installed for advance warning purposes. ....	16

## LIST OF PROCEDURAL REQUIREMENTS

Topic	Subject	Page
<b>CHAPTER 1 - METERED ENTRANCE RAMP AND CONNECTORS</b>		
1.2	<i>Any proposed three-lane loop or four-lane entrance ramp requires the review and concurrence of the Caltrans Headquarters Traffic Operations Liaison and approval by Deputy District Director of Traffic Operations. ....</i>	2
1.4	<i>Storage length design requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering. ....</i>	3
1.7	<i>The location of a limit line requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering. ....</i>	4
1.8	<i>Design of the HOV preferential lane at a metered entrance ramp requires the review and concurrence of the District Traffic Operations Branch responsible for ramp metering. ....</i>	4
1.9	<i>Conversion of an HOV preferential lane to a GP lane at a metered entrance ramp requires preparation of an Exception(s) to Ramp Metering Policy Fact Sheet, which must be concurred with by the Caltrans Headquarters Traffic Operations Liaison or the designated representative and must be approved by Deputy District Director of Traffic Operations ....</i>	4
1.10	<i>Contact the CHP Area Commander as early as possible during the project development process, prior to plan preparation, to discuss any significant variations to the enforcement area design shown in the RMDM. Variations to enforcement area dimension or location require the review and concurrence of the CHP and the Caltrans District Traffic Operations Branch responsible for ramp metering. ....</i>	5
1.10	<i>The location and the design of an MVP at a metered entrance ramp requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering. ....</i>	5
<b>CHAPTER 2 - HARDWARE AND SYSTEM INTEGRATION</b>		
2.1	<i>The ramp metering hardware and systems shown in design plans require the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering to determine if additional hardware or system elements are required before the plans are approved. ....</i>	12
2.3.1	<i>For other detection technology, consult with the Caltrans District Traffic Operations Branch responsible for ramp metering. ....</i>	13

2.3.1	<i>The preferred type, number, and locations for all mainline, entrance ramp, and exit ramp loop detectors require the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering. ....</i>	13
2.3.5	<i>For additional queue detectors, consult with the Caltrans District Traffic Operations Branch responsible for ramp metering. ....</i>	14
2.4	<i>The exact number and location of controller cabinets requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering. ....</i>	15
2.5	<i>When wireless communication is proposed, the choice of integrated wireless communications equipment requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for electrical systems. ....</i>	15
2.5	<i>The telephone service requirements and the exact location requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for electrical systems, in coordination with the affected specific telephone provider involved. ....</i>	15
2.5	<i>When installing network equipment for Internet Protocol (IP) addressable controllers, the connections to fiber network and integration with the Transportation Management Center (TMC) network require the review and concurrence of the Caltrans District Traffic Operations Branch responsible for electrical systems. Network security requires that all field elements communicate with the central system via a transmission control protocol (TCP)/IP connection ....</i>	15
2.6.1	<i>The type and number of advance warning devices require the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering. ....</i>	16
2.6.2	<i>Supporting structures other than those shown in Caltrans' latest Standard Plans require the review and approval by Caltrans Division of Engineering Services. The exact placement of the advance warning devices requires the review and concurrence of Caltrans District Traffic Operations Branch responsible for ramp metering. ....</i>	17
2.8	<i>The use of a temporary entrance ramp meter requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering. ....</i>	17

**CHAPTER 3 - SIGNING AND PAVEMENT MARKINGS**

3.1 *Exceptions to the aforementioned publications and proposed evaluation of other signs and markings require the review and concurrence of Caltrans Headquarters Traffic Operations, Office of Traffic Engineering. ....* 31

3.1 *The number, size, and location of signs and pavement markings require the review and concurrence of Caltrans District Traffic Operations Branch responsible for ramp metering. ....* 31

3.2.4 *Obtain the concurrence of the local agencies and the Caltrans District Traffic Operations Branch responsible for signing and pavement markings before installing signs on local roadways. ....* 33

This page is intentionally left blank.

# CHAPTER 1

## METERED ENTRANCE RAMPS AND CONNECTORS

### 1.1 Introduction

Caltrans Deputy Directive 35-R1 contains the statewide policy for ramp metering and delegates responsibilities for implementation. Proposed projects within freeway segments that have existing or proposed ramp meters listed in the latest version of Caltrans *Ramp Metering Development Plan* (RMDP) shall include provisions for ramp metering. Projects designed for new or existing freeway segments without ramp meters, but experiencing recurring traffic congestion and/or having a high frequency of vehicle collisions may consider adding ramp meters.

Geometric design of metered entrance ramps must comply with the standards contained in *Caltrans Highway Design Manual* (HDM). Design of new entrance ramps is typically based on the projected peak-hour traffic volume 20 years after completion of construction, except as stated in the HDM Index 103.2. As with all highway projects, the safety and mobility needs of travelers of all ages and abilities must be addressed in a manner consistent with Caltrans Deputy Directive 64-R2, Complete Streets.

The entrance to a metered entrance ramp should accommodate the crossing of non-motorized traffic (i.e., pedestrians and bicyclists), especially when the entrance ramp is located near schools or a local roadway facility with a designated bicycle lane or route. Non-motorized traffic crossings may be marked or unmarked. Sight distance should be considered in the placement of the non-motorized traffic crossing. Refer to the HDM Topic 201 for sight distance guidance.

Designers need to refer to the HDM for all geometric-related design standards that apply to ramp metering. Any deviations from geometric related design standards need to be approved in accordance with HDM Index 82.2 and the *Project Development Procedures Manual* (PDPM) Chapter 21.

### 1.2 Number of Metered Entrance Ramp Lanes

For a typical one vehicle per green operation, a ramp meter has practical lower and upper output limits of 240 and 900 vehicles per hour (VPH) per lane, respectively. Ramp metering signals set for flow rates outside this range tend to have high violation rates and cannot effectively control traffic. Therefore, a minimum of one metered lane must be provided for every 900 VPH of traffic demand. However, two General Purpose (GP) lanes may be considered to increase queue storage within the available ramp length when entrance ramp peak hour volumes exceed 500 VPH. See section 1.4 Queue Storage Length Design.

The number of metered lanes at an entrance ramp is determined from the number of lanes at the limit line. It includes the number of both metered general purpose (GP) and high-occupancy vehicle (HOV) preferential lanes. The minimum number of metered GP lanes is determined based on GP traffic demand. The number of metered HOV preferential lanes is determined based on HOV demand using the same guidelines as GP traffic demand, as well as the HOV preferential lane policy.

HOV preferential lanes shall be provided wherever ramp meters are installed, and each HOV preferential lane should be metered.

Ramp Metering design exception approval must be obtained prior to district approval of any project initiation documents such as Project Study Reports (PSR), Project Scope Summary Reports (PSSR), Permit Engineering Evaluation Reports (PEER), or combined PSR and Project Reports (PR). See Appendix A for Deputy Directive 35-R1. See Appendix B for *Exception(s) to Ramp Metering Policy Fact Sheet*. See Appendix C for a ramp metering design checklist.

For new or reconstructed metered entrance ramps, the minimum number and type of entrance ramp lanes as specified in Table 1-1 shall be provided. When truck demand accounts for more than five percent of the GP traffic demand, truck volume must be converted to passenger-car equivalents before using Table 1-1.

**Table 1-1 Minimum Number and Type of Entrance Ramp Lanes (for a typical one vehicle per green operation)**

Peak Hour GP Lane Volume, VPH	Minimum Number of Entrance Ramp Lanes	Illustration
≤900	1 GP + 1 HOV <sup>(1)</sup>	Fig. 1-1, 1-2, and 1-5
>900 but ≤1,800	2 GP + 1 HOV <sup>(1)</sup>	Fig. 1-3, 1-4 <sup>(2)</sup> , and 1-6
>1,800	3 GP + 1 HOV <sup>(1)</sup>	(2)

<sup>(1)</sup> Increase the number of HOV lanes based on HOV demand.

<sup>(2)</sup> Obtain concurrence of the Caltrans Headquarters Traffic Operations Liaison for three-lane loop or four-lane entrance ramps.

See figures 1-1 and 1-2 for the typical two-lane metered entrance ramp designs (one GP lane and one HOV preferential lane). See figures 1-3 and 1-4 for the typical three-lane metered entrance ramp designs (two GP lanes and one HOV preferential lane).

*Any proposed three-lane loop or four-lane entrance ramp requires the review and concurrence of the Caltrans Headquarters Traffic Operations Liaison and approval by Deputy District Director of Traffic Operations.*

### 1.3 Lane Width and Shoulder Width

For metered entrance ramps and connectors, lane width and shoulder width shall be designed according to the requirements as specified in HDM Chapter 300 and Chapter 500.

### 1.4 Queue Storage Length Design

Storage length is an integral part of a metered entrance ramp. It provides a place upstream of the limit line for queued vehicles during metering operations. To keep the connected local roadways free from the adverse impacts of the entrance ramp queue overspill, adequate storage length should be provided to contain the entrance ramp queue within the entrance ramp. A metered entrance

ramp may have to be widened or lengthened in order to provide adequate storage length.

For existing entrance ramps, the adequacy of entrance ramp storage length can be evaluated using the existing peak period 5, 6, or 15 minute arrival rates and the existing or anticipated ramp meter discharge rates. See Appendix D for a detailed description of the Arrival-Discharge Chart method. The arrival-discharge chart method is not to be used for storage design of new or reconstructed entrance ramps.

For a new or reconstructed entrance ramp, the minimum storage length should be designed based on seven percent (7%) of the peak hour demand for the design year. The storage length for the GP and HOV lanes is calculated separately based on the respective peak hour traffic demand. The GP lane demand is the total entrance ramp peak hour demand minus the HOV demand. The HOV demand may vary widely; thus current and project-specific HOV demand information is necessary.

The observed average vehicle spacing for each queued vehicle at a metered entrance ramp is 29 feet, measured from front of one vehicle to the front of the next vehicle. Greater average vehicle spacing should be considered for metered entrance ramps on long and substantial downgrades, or metered entrance ramps that serve a significant percentage of trucks, buses, or recreational vehicles.

For example, the calculation below determines the minimum storage length for each GP lane at a metered entrance ramp with two GP lanes and one HOV preferential lane when the total peak hour traffic demand is 1,200 VPH and 15 percent HOV traffic. In the calculation, the two GP lanes are assumed to be used equally by traffic. A minimum storage length of 1,035 feet is needed for each GP lane.

$$\frac{100\% - 15\% \text{ HOV volume} = 85\% \text{ GP volume}}{2 \text{ GP lanes}} \times (1,200 \text{ veh}) \times (85\% \text{ GP vol}) \times (29 \frac{\text{ft}}{\text{veh}})$$

$$\text{minimum GP storage length} = 1,035 \frac{\text{ft}}{\text{lane}}$$

The minimum storage length necessary for the HOV preferential lane can be calculated using the same method to attain a value of 365 feet.

$$\frac{7\% \times (1,200 \text{ veh}) \times (15\% \text{ HOV vol}) \times (29 \text{ ft/veh})}{1 \text{ HOV lane}}$$

mimimum HOV storage length = 365 ft/lane

The HOV preferential lane should be designed to match the length of the adjacent GP lane(s). This allows HOV traffic earlier access to the HOV lane without queuing in the GP lane(s).

Local streets in the vicinity of a metered entrance ramp may be improved to provide more queue storage when the traffic demand exceeds available storage length at the entrance ramp. Local street improvements may include widening or lengthening existing roadways or intersections to provide additional storage capacity for the appropriate movements. Adjusting the signal timing at upstream intersections that direct traffic to the entrance ramp also helps to mitigate arrivals of platoons. These improvements require coordination with local agencies to be consistent with the regional traffic operations strategies. The ideal strategy would be a system-wide adaptive ramp metering system that coordinates with local roadway signal systems.

It is the responsibility of the ramp metering project engineer to mitigate the initial as well as future impacts of ramp metering on local roadways. It is the responsibility of the developers and/or local agencies to mitigate the impacts on existing ramp metering operations as a result of local development and/or local agency roadway improvement projects.

*Storage length design requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering.*

### 1.5 Ramp Metering Deceleration Distance

In addition to queue storage length, the vehicle deceleration distance to the back of traffic queues should also be a part of the length of a metered entrance ramp upstream from the queue storage length. The ramp metering deceleration distance is the stopping distance required for the

approaching traffic to decelerate and stop clear of the back of traffic queues in a controlled manner. Use the design speed of the entrance ramp or the connecting roadways as the approaching speed to the back of queue. Refer to HDM Topic 201 for more information on how to determine stopping sight distance.

### 1.6 Ramp Metering Acceleration Distance

The ramp metering acceleration distance is the distance downstream from the limit line that vehicles need to accelerate to reach the merging speed. It may include the lane-drop taper and auxiliary lane length up to the beginning of the merging taper. A minimum of a 300 feet long auxiliary lane shall be provided beyond the ramp convergence point. Metered vehicles start to accelerate from a stopped position at the limit line. As specified in Chapter 10, "Grade Separations and Interchanges," of AASHTO's 2011 *A Policy on Geometric Design of Highways and Streets*, the entrance ramp traffic merging speed should be within 5 mph of the freeway mainline operating speed. The acceleration value used should be commensurate with the selected design vehicles. Specifically, Exhibit 10-70 of the AASHTO's 2011 *A Policy on Geometric Design of Highways and Streets* specifies the minimum acceleration lengths for entrance terminals with grades of two percent or less, while Exhibit 10-71 provides speed change lane adjustment factors as a function of grade. Refer to Chapter 500 of the HDM for detailed geometric design guidance related to lane-drop taper, auxiliary lane, and merging taper.

### 1.7 Limit Line Location

The limit line is where metered vehicles stop and wait for the metering signal cycle before accelerating to merging speed. At metered entrance ramps, the limit line separates the ramp's upstream segment, which includes the queue storage length and the deceleration distance, from the downstream segment, which includes the acceleration distance and the merging taper. The location of the limit line should maximize the available storage length and provide sufficient acceleration distance for a vehicle to reach its merging speed from a complete stop. See section 1.4 Queue Storage Length Design on how to

calculate the minimum storage length and section 1.6 Ramp Metering Acceleration Distance on how to calculate the required acceleration distance.

For multi-lane metered entrance ramps, the location of the limit line should take into consideration the length of each lane-drop transition taper. However, regardless of the number of lanes, the limit line should be located a minimum of 75 feet upstream of the 23-foot separation point. See Figures 1-1 to 1-6 for the typical locations of limit lines. See section 3.3 Pavement Markings for guidance on limit line pavement markings.

*The location of a limit line requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering.*

### 1.8 HOV Preferential Lanes

Placement of an HOV preferential lane at a metered entrance ramp encourages ridesharing by carpooling, vanpool, and transit to reduce congestion. The HOV preferential lane at a metered entrance ramp, as stated in Caltrans' Deputy Directive 35-R1, should be metered. The typical minimum vehicle occupancy requirement for the HOV preferential lane is two persons or more per vehicle. At some locations, a higher minimum vehicle occupancy requirement may be necessary. The occupancy requirement is determined by the HOV facility on the mainline.

The HOV preferential lane is typically placed on the left side of the entrance ramp. However, traffic demand and operational characteristics at the ramp entrance may dictate otherwise.

Access to the HOV preferential lane may be provided in a variety of ways depending on the interchange type and available storage length for queued vehicles. Where queued vehicles in the GP lane may block access to the HOV preferential lane, consider providing direct or separated access. To avoid trapping GP traffic into an HOV preferential lane, the signing and pavement marking at the ramp entrance should direct motorists into the GP lane(s). Refer to Chapter 3 for HOV preferential lane signs and pavement markings.

Similar to the GP lanes, the entrance to the HOV preferential lane should also accommodate the crossing of non-motorized traffic. In the design illustrated in Figure 3-6, the HOV preferential lane starts downstream of the at-grade intersection so that the crossing distance for non-motorized traffic is reduced.

*Design of the HOV preferential lane at a metered entrance ramp requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering.*

### 1.9 Converting HOV Preferential Lanes to GP Lanes

Changes in traffic conditions, modifications of interchanges, recurrent operational issues affecting the local facility, or the need to further improve mainline operations through more restrictive metering are several opportunities to reevaluate the need for HOV preferential lanes. Typically, an existing HOV preferential lane may be considered for conversion to a GP lane if the existing HOV preferential lane is under-utilized, there is a need for additional queue storage for the GP lanes, or an alternate entrance ramp HOV preferential lane is available within 1.5 miles.

*Conversion of an HOV preferential lane to a GP lane at a metered entrance ramp requires preparation of an Exception(s) to Ramp Metering Policy Fact Sheet, which must be concurred with by the Caltrans Headquarters Traffic Operations Liaison or the designated representative and must be approved by Deputy District Director of Traffic Operations.*

### 1.10 Enforcement Areas and Maintenance Vehicle Pullouts

A paved enforcement area shall be incorporated into the design of all projects that include new or reconstructed metered entrance ramps or connectors.

Enforcement areas are used by California Highway Patrol (CHP) officers to enforce ramp metering signal violations and HOV preferential lane minimum vehicle occupancy requirements.

The paved enforcement area should be placed on the right side of a metered entrance ramp, downstream of the metering signals, and as close to the limit line as practical to facilitate CHP enforcement. See Figures 1-1 to 1-6 for the typical layout and dimensions of enforcement areas. The enforcement areas should not be placed in gore areas or at locations that are susceptible to objects thrown from above such as under bridge overcrossings.

*Contact the CHP Area Commander as early as possible during the project development process, prior to plan preparation, to discuss any significant variations to the enforcement area design shown in the RMDM. Variations to enforcement area dimension or location require the review and concurrence of the CHP and the Caltrans District Traffic Operations Branch responsible for ramp metering.*

A paved Maintenance Vehicle Pullout (MVP) shall be incorporated into the design of all projects that include new or reconstructed metered entrance ramps or connectors.

A paved MVP is used to provide a convenient location for maintenance and operations personnel to access controller cabinets. The MVP should be placed upstream or next to the controller cabinets. The MVP and the controller cabinets should be placed on the same side of the entrance ramp so that maintenance and operations personnel do not need to cross live traffic to access the cabinet. At loop entrance ramps, locate the MVP to the inside of the loop ramp. A paved walkway should be provided between the MVP and the controller cabinets. See section 2.4 for a description of controller cabinet placement. Refer to HDM Index 107.2 and the Standard Plans H9 for the layout and pavement structural section details of an MVP.

*The location and the design of an MVP at a metered entrance ramp requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering.*

### **1.11 Metered Freeway-to-Freeway Connectors**

Freeway-to-freeway connectors may also be metered when warranted. The need to meter a connector should be determined on an individual basis. The installation of ramp meters on connector ramps shall be limited to those facilities which meet or exceed specific geometric design criteria provided in HDM Index 504.3(2)(c). Since freeway-to-freeway connectors operate at higher speeds and volumes, sight distances, queue storage lengths, and advance warning devices are even more critical.

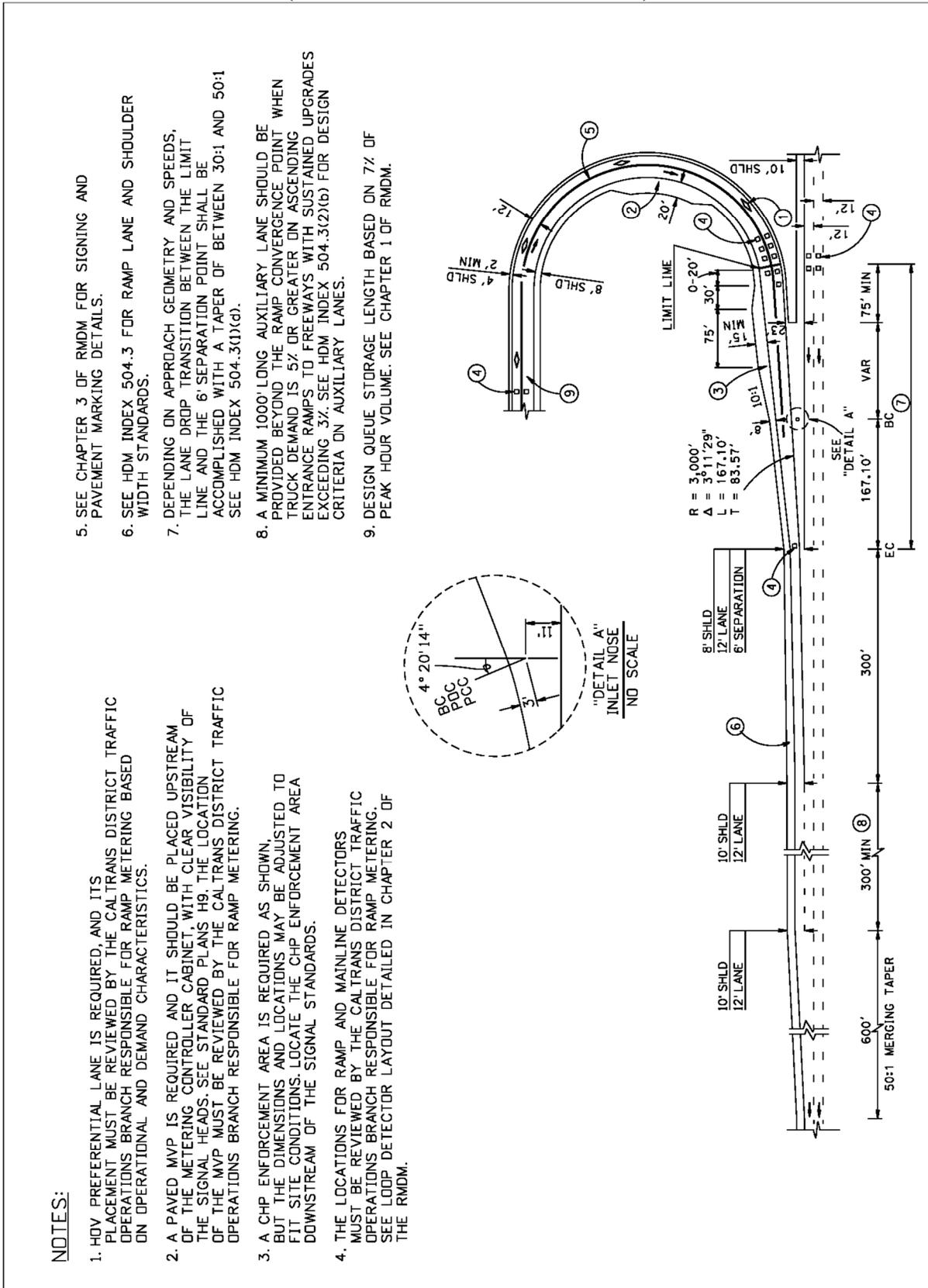
Unless noted otherwise, the policies and standards for freeway-to-freeway connector metering are the same as ramp metering. The minimum number and type of metered lanes are specified in Table 1-1. See Figures 1-5 and 1-6 for the typical layout of two-lane and three-lane connector metering, respectively.

Refer to HDM Index 504.4 for more guidance on lane width, shoulder width, lane-drop taper, merging taper, auxiliary lane, metering, and sight distance design.

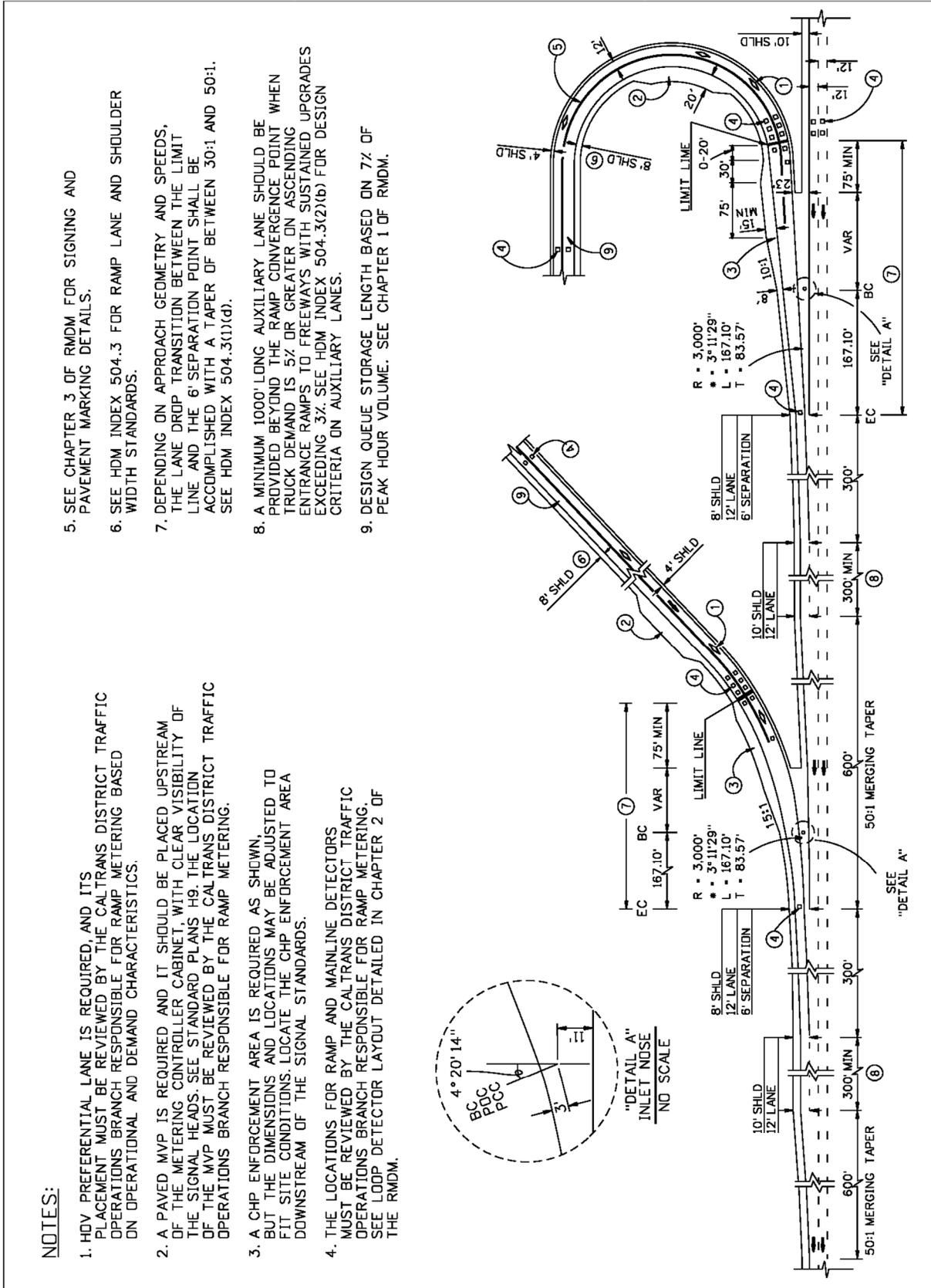
When a freeway-to-freeway connector is metered, an HOV preferential lane shall be provided, and the HOV preferential lane should be metered.

Direct HOV-to-HOV connectors may be constructed to minimize weaving operations and improve traffic operations.

**Figure 1-1**  
**Typical 2-Lane Metered Freeway Loop Entrance Ramp**  
 (1 GP Lane + 1 HOV Preferential Lane)



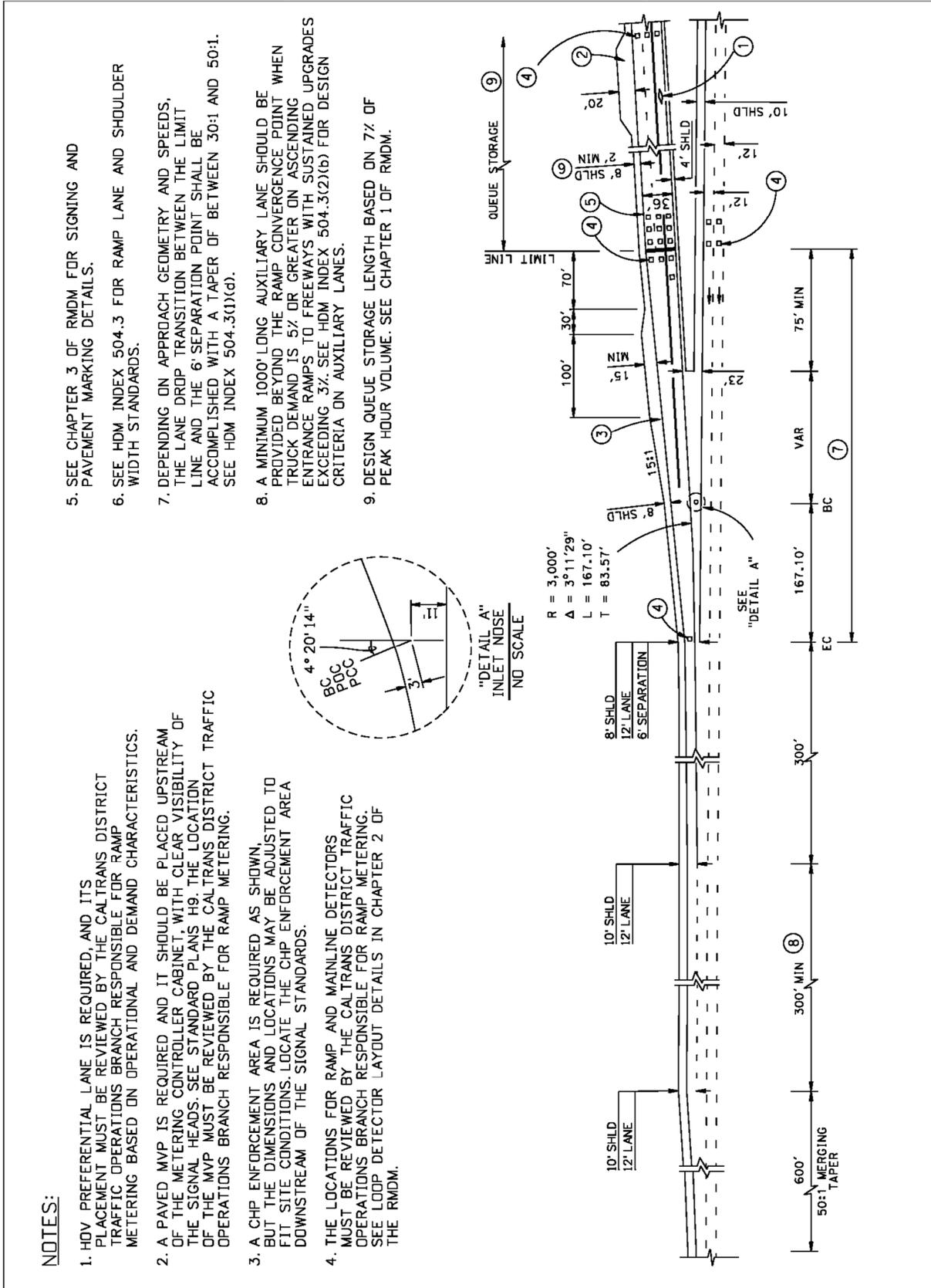
**Figure 1-2**  
**Typical 2-Lane Metered Successive Freeway Entrance Ramps**  
 (1 GP Lane + 1 HOV Preferential Lane)



**NOTES:**

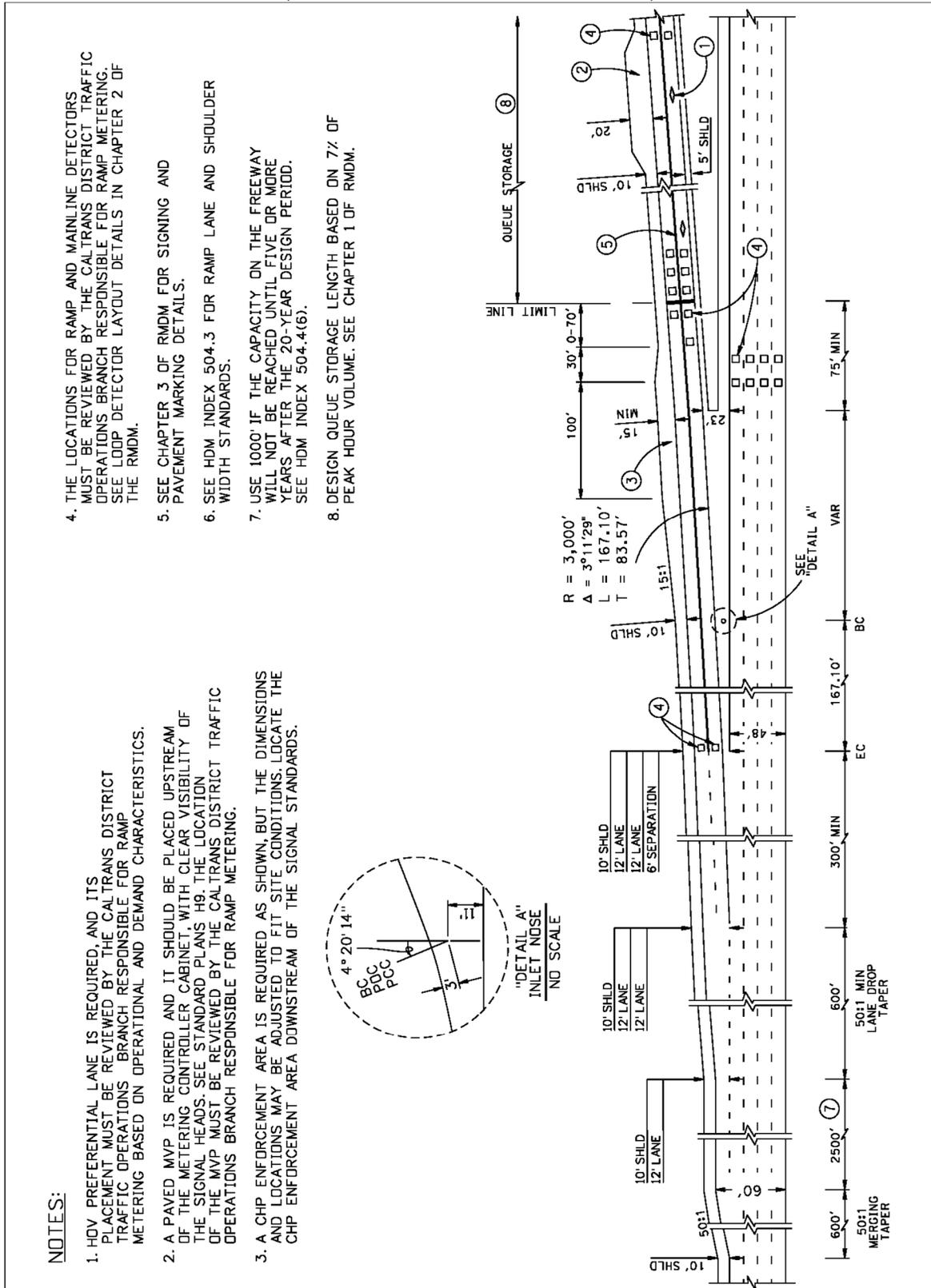
1. HOV PREFERENTIAL LANE IS REQUIRED, AND ITS PLACEMENT MUST BE REVIEWED BY THE CALTRANS DISTRICT TRAFFIC OPERATIONS BRANCH RESPONSIBLE FOR RAMP METERING BASED ON OPERATIONAL AND DEMAND CHARACTERISTICS.
2. A PAVED MVP IS REQUIRED AND IT SHOULD BE PLACED UPSTREAM OF THE METERING CONTROLLER CABINET, WITH CLEAR VISIBILITY OF THE SIGNAL HEADS. SEE STANDARD PLANS H-9. THE LOCATION OF THE MVP MUST BE REVIEWED BY THE CALTRANS DISTRICT TRAFFIC OPERATIONS BRANCH RESPONSIBLE FOR RAMP METERING.
3. A CHP ENFORCEMENT AREA IS REQUIRED AS SHOWN, BUT THE DIMENSIONS AND LOCATIONS MAY BE ADJUSTED TO FIT SITE CONDITIONS. LOCATE THE CHP ENFORCEMENT AREA DOWNSTREAM OF THE SIGNAL STANDARDS.
4. THE LOCATIONS FOR RAMP AND MAINLINE DETECTORS MUST BE REVIEWED BY THE CALTRANS DISTRICT TRAFFIC OPERATIONS BRANCH RESPONSIBLE FOR RAMP METERING. SEE LOOP DETECTOR LAYOUT DETAILED IN CHAPTER 2 OF THE RMDM.
5. SEE CHAPTER 3 OF RMDM FOR SIGNING AND PAVEMENT MARKING DETAILS.
6. SEE HDM INDEX 504.3 FOR RAMP LANE AND SHOULDER WIDTH STANDARDS.
7. DEPENDING ON APPROACH GEOMETRY AND SPEEDS, THE LANE DROP TRANSITION BETWEEN THE LIMIT LINE AND THE 6' SEPARATION POINT SHALL BE ACCOMPLISHED WITH A TAPER OF BETWEEN 30:1 AND 50:1. SEE HDM INDEX 504.3(1)(d).
8. A MINIMUM 1000' LONG AUXILIARY LANE SHOULD BE PROVIDED BEYOND THE RAMP CONVERGENCE POINT WHEN TRUCK DEMAND IS 5% OR GREATER ON ASCENDING ENTRANCE RAMP TO FREEWAYS WITH SUSTAINED UPGRADES EXCEEDING 3%. SEE HDM INDEX 504.3(2)(b) FOR DESIGN CRITERIA ON AUXILIARY LANES.
9. DESIGN QUEUE STORAGE LENGTH BASED ON 7% OF PEAK HOUR VOLUME. SEE CHAPTER 1 OF RMDM.

**Figure 1-3**  
**Typical 3-Lane Metered Freeway Diagonal Entrance Ramp**  
 (2 GP Lanes + 1 HOV Preferential Lane)





**Figure 1-5**  
**Typical 2-Lane Metered Connector**  
 (1 GP Lane + 1 HOV Preferential Lane)



**NOTES:**

1. HOV PREFERENTIAL LANE IS REQUIRED, AND ITS PLACEMENT MUST BE REVIEWED BY THE CALTRANS DISTRICT TRAFFIC OPERATIONS BRANCH RESPONSIBLE FOR RAMP METERING. SEE LOOP DETECTOR LAYOUT DETAILS IN CHAPTER 2 OF THE RMDM.
2. A PAVED MVP IS REQUIRED AND IT SHOULD BE PLACED UPSTREAM OF THE METERING CONTROLLER CABINET, WITH CLEAR VISIBILITY OF THE SIGNAL HEADS. SEE STANDARD PLANS H9. THE LOCATION OF THE MVP MUST BE REVIEWED BY THE CALTRANS DISTRICT TRAFFIC OPERATIONS BRANCH RESPONSIBLE FOR RAMP METERING.
3. A CHP ENFORCEMENT AREA IS REQUIRED AS SHOWN, BUT THE DIMENSIONS AND LOCATIONS MAY BE ADJUSTED TO FIT SITE CONDITIONS. LOCATE THE CHP ENFORCEMENT AREA DOWNSTREAM OF THE SIGNAL STANDARDS.
4. THE LOCATIONS FOR RAMP AND MAINLINE DETECTORS MUST BE REVIEWED BY THE CALTRANS DISTRICT TRAFFIC OPERATIONS BRANCH RESPONSIBLE FOR RAMP METERING. SEE LOOP DETECTOR LAYOUT DETAILS IN CHAPTER 2 OF THE RMDM.
5. SEE CHAPTER 3 OF RMDM FOR SIGNING AND PAVEMENT MARKING DETAILS.
6. SEE HDM INDEX 504.3 FOR RAMP LANE AND SHOULDER WIDTH STANDARDS.
7. USE 1000' IF THE CAPACITY ON THE FREEWAY WILL NOT BE REACHED UNTIL FIVE OR MORE YEARS AFTER THE 20-YEAR DESIGN PERIOD. SEE HDM INDEX 504.4(6).
8. DESIGN QUEUE STORAGE LENGTH BASED ON 7% OF PEAK HOUR VOLUME. SEE CHAPTER 1 OF RMDM.



## CHAPTER 2

# HARDWARE AND SYSTEM INTEGRATION

### 2.1 Introduction

At a minimum, ramp metering hardware elements shall include signal heads and standards, traffic detectors, controller assemblies, advance warning devices, and communication systems. Some locations may require additional hardware elements. The typical layouts of these elements for an L-9 and a full-cloverleaf interchange are shown in Figures 2-1 and 2-2, respectively. The placement of signal standards, advance warning device supporting structures, and controller assemblies must meet the roadside clear recovery zone (CRZ) standards set forth in HDM Topic 309. Guardrail or barrier should be considered where ramp metering hardware elements are placed within the CRZ. All new ramp metering systems must be integrated into the Transportation Management Center (TMC). Theft prevention strategies to protect ramp metering field hardware elements, including conductors, shall be considered in the project development process. The wire-theft prevention toolbox is located at: <http://traffic.onramp.dot.ca.gov/wire-theft-prevention>

*The ramp metering hardware and systems shown in design plans require the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering to determine if additional hardware or system elements are required before the plans are approved.*

### 2.2 Signal Standards and Heads

#### 2.2.1 Signal Standards

Ramp metering signals may be roadside-mounted using Type 1 standards, or overhead-mounted using mast arms. The signal standards should be placed on the right side of the entrance ramp to help reduce maintenance personnel exposure to live traffic at the entrance of the gore area. However, Type 1 standards may need to be installed on the left side of the entrance ramp to provide the necessary sight distance for the approaching motorists. This typically occurs at loop entrance ramps where the roadway curvature limits the visibility of the overhead-mounted signal heads located downstream

of the limit line. To evaluate the available stopping sight distance, use the entrance ramp design speed as the approaching speed, and assume the approaching motorists have a 20-degree cone of vision and a perception-response time (PRT) of 2.5 seconds, see Section 2C.05 of the California Manual on Uniform Traffic Control Devices (CA MUTCD). See HDM Topic 201 for sight distance calculations. Refer to the current version of the CA MUTCD, Section 4D “Traffic Control Signal Features,” for the minimum sight distance required for signal visibility.

For a single lane metered loop entrance ramp, install one Type 1 standard on the left side of the entrance ramp to provide the necessary sight distance for the approaching motorists. For a single lane metered diagonal entrance ramp, install one Type 1 standard on the right side of the entrance ramp. However, for certain ramp geometries (i.e., ramps with long entrance lengths, steep grades, or limited stopping sight distances) or metering operational characteristics (i.e., ramps with high traffic demand, a high percentage of truck traffic, or high approaching speeds), it may be more appropriate to install a mast arm standard for a single-lane entrance ramp to enhance the visibility of the signal heads. If a mast arm standard is selected, it should be placed on the right side of the entrance ramp. Nevertheless, the implementation of a single-lane metered entrance ramp requires an Exception (s) to Ramp Metering Policy as specified in section 1.2 “Number of Metered Entrance Ramp Lanes”.

For a two-lane metered loop entrance ramp, install one Type 1 standard on each side of the entrance ramp at the limit line. For a two-lane metered diagonal entrance ramp, install one mast arm standard on the right side of the entrance ramp, downstream of the limit line. Type 1 standards may be considered if placed outside the mainline CRZ.

For a metered entrance ramp with three or more lanes, install one mast arm standard downstream of the limit line on the right side of the entrance ramp. In addition to the mast arm standard, Type 1 standards should also be installed on each side of the entrance ramp at the limit line, especially when the sight distance to the mast arm-mounted signal heads is limited.

Type 1 standards should be located a minimum of 12 inches downstream of the trailing edge of the limit line and 4 feet offset from the edge of the shoulder. A mast arm standard should be placed a minimum of

70 feet downstream of the limit line on the right side of the entrance ramp to minimize knock-downs.

Refer to Figures 2-3 and 2-4 for the typical installation of Type 1 and mast arm standards, respectively. See Figure 2-5 for the typical signal standard placement at loop entrance ramps, and Figure 2-6 for the typical signal standard placement at diagonal entrance ramps.

### 2.2.2 Signal Heads

Use three-section signal heads for ramp metering purposes. The three sections, arranged vertically from top to bottom, display the red, yellow, and green indication respectively. Programmable visibility (PV) heads may be installed to limit the visibility from mainline traffic. However, freeway connectors or long entrance ramps with limited sight distance or high-speed approach traffic may require the use of non-PV heads for better visibility. When a Type 1 standard is used, attach two signal heads, one upper and one lower, to the standard. Use 12-inch diameter sections for the upper head, and either 12-inch or 8-inch diameter sections for the lower head. Position the upper head to face the approaching vehicles, and the lower head to face the vehicle stopped at the limit line. In the presence of a concrete barrier or metal-beam guardrail alongside of an entrance ramp where the Type 1 standard is located, a minimum of 15 inches of clearance must be maintained between the top edge of the barrier/guardrail and the bottom of the signal backplate.

When a mast arm supporting structure is used, install one signal head with 12-inch diameter sections over the center of each metered lane. In addition to the signal heads mounted on the mast arm, Type 1 standards with both upper and lower heads may be installed at the limit line to facilitate metering operations. Sound walls or other structures may restrict the room to place a stand-alone signal supporting structure at an entrance ramp. Signal heads may be mounted directly onto the structure using a special wall-mounting design.

For enforcement purposes, install a single-section signal head with an 8-inch diameter red section (signal status indicator) on the backside of each upper signal head (including those mounted on mast arms) for each metered lane, as shown in Figures 2-3 and 2-4.

### 2.2.3 Limit Line Lighting

Limit line lighting may be provided to illuminate the limit line during pre-dawn or post-dusk hours. Lighting standards, such as Type 15, may be used. Refer to Caltrans' *Signal, Lighting, and Electrical Systems Design Guide* for related limit line lighting information.

## 2.3 Detectors

### 2.3.1 General

Inductive loop detectors are used for traffic detection at freeway mainlines, entrance ramps, and exit ramps to gather the speed, volume, and occupancy data necessary to monitor freeway performance and establish metering rates. Other detection technology may be used as long as it provides the same level of accuracy, precision, cost-effectiveness, and reliability. *For other detection technology, consult with the Caltrans District Traffic Operations Branch responsible for ramp metering.* For ramp metering applications, use either Type A or Type E inductive loop detectors at the mainline, entrance ramp and exit ramp. However, use only one type of loop detector for each detector station.

Each detector should be centered in each lane unless otherwise noted. Location of the detectors shall be adjusted to avoid transverse pavement joints or structures. Location of the detectors should also be adjusted to keep a minimum of 10 feet of clearance from any manhole, water valve, or other appurtenances located within the roadway. Terminate the detectors in the nearest and most appropriate ramp metering controller cabinet. Refer to Caltrans Standard Plans for detailed configuration and installation procedures of the various types for loop detectors.

*The preferred type, number, and locations for all mainline, entrance ramp, and exit ramp loop detectors require the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering.*

### 2.3.2 Mainline Detectors

For ramp metering operation, two mainline detectors of the same type shall be installed in each freeway mainline lane as illustrated in Figure 2-7. The spacing between the two detectors shall be 20 feet from leading edge to leading edge. If a count

detector is installed, the mainline detectors should be positioned aligning laterally with the count detector. See section 2.3.6 Count Detectors. Otherwise, position the mainline loop detectors upstream of the entrance ramp gore nose opposite the limit line as shown in Figures 2-1 and 2-2. The placement shall avoid locations with varied lane width.

### 2.3.3 Entrance Ramp Demand Detectors

Demand detectors shall be installed upstream of the limit line in each metered lane as shown in Figures 2-8 and 2-9, including the HOV preferential lane. A minimum of three loop detectors shall be used for each demand detector. Wire the demand loop detectors in series-parallel so that the demand detectors remain functional even when some of the loop detectors fail. Wider loop detectors should be considered where the lane width is greater than 12 feet, or when the vehicle's travel path favors the inside edge of the traveled way, such as at loop entrance ramps.

### 2.3.4 Entrance Ramp Passage Detectors

A passage detector confirms the crossing of the limit line of the metered vehicles. It also counts the number of vehicles entering the mainline. One passage detector shall be provided 7 feet downstream of the limit line in each metered lane as shown in Figures 2-8 and 2-9. Wider loop detectors should be considered where the lane width is greater than 12 feet, or when the vehicle's travel path favors the inside edge of the traveled way, such as at loop entrance ramps.

### 2.3.5 Entrance Ramp Queue Detectors

For entrance ramp queue monitoring and control purposes, install one queue detector per metered lane, including the HOV preferential lane, when metered. The queue detector is typically installed near the beginning of the entrance ramp. When the queue detector identifies a potential ramp metering queue overflow, it activates the 'queue override' metering rate to shorten the length of the entrance ramp queue.

As illustrated in Figures 2-8 and 2-9, additional queue detectors may be deployed further along the entrance ramp. Queue detectors may be installed in the middle or three-quarter point of the entrance ramp to enhance monitoring of the progression of entrance ramp queues. Queue detectors may also be

installed at the turning pockets of connected roadways for similar purposes.

*For additional queue detectors, consult with the Caltrans District Traffic Operations Branch responsible for Ramp Metering. The approval of the local highway agencies must be secured before locating queue detectors on local roadways.*

### 2.3.6 Count Detectors

If the entrance ramp passage detectors do not acquire traffic count information, count detectors shall be installed. When installing count detectors at single lane entrance ramps, locate the count detector downstream of the passage detector but upstream of the 6-foot separation point, where traffic starts to merge onto the mainline in order to capture all entrance ramp vehicles entering the freeway. When installing count detectors at multi-lane entrance ramps, locate the count detector downstream of the lane-drop taper, but upstream of the 6-foot separation point. A wider detector may be necessary to increase traffic count accuracy.

One additional count detector should be provided for the HOV preferential lane. Position the detector downstream of the HOV preferential lane passage detector, free of interference of any GP lane traffic, to provide an accurate count of the HOV lane traffic entering the freeway mainline. See Figures 2-8 and 2-9 for the placement of the HOV preferential lane count detectors.

### 2.3.7 Exit Ramp Detectors

As shown in Figure 2-10, one exit ramp detector per exit ramp lane shall be installed to count vehicles exiting the freeway mainline. The exit ramp detectors should be positioned at the 23-foot separation point downstream of the diverging point. If an exit ramp bifurcates, separate loop detectors should be installed for each exit ramp lane immediately downstream of the bifurcation point. Refer to Figure 2-2 for the typical detector layout at a full cloverleaf interchange with collector-distributor road design.

### 2.3.8 Detectors at Metered Connectors

A metered connector requires the same detectors as a metered entrance ramp. A general layout of these detectors is shown in Figure 2-11. One set of queue detectors shall be placed near the entrance to the

connector. Additional queue detectors may be deployed further downstream and upstream of the entrance. Further downstream, queue detectors may be installed where sight distance is limited to provide additional queue monitoring. Further upstream queue detectors may be installed at freeway mainlines for similar purposes.

## 2.4 Controller Cabinets

For each entrance ramp with ramp meters, one State-furnished controller cabinet shall be installed to house the State-furnished traffic controller, detector sensor units, power distribution assembly, load switches, and appropriate communications equipment. All associated mainline, entrance ramp, and exit ramp detectors should terminate into the controller cabinet. Up to four entrance ramp lanes can be controlled by one controller. Loop detectors shall not be installed over 3,000 feet from the controller cabinet.

Each controller cabinet shall be furnished with 120-Volts Alternating Current (VAC) power service with separate circuit breakers rated for a minimum of 30 Amperes. It is the responsibility of the Project Engineer to perform a field review and work with service utility entities to establish the service points.

The placement of each controller cabinet should minimize the possibility of being hit by errant vehicles and should meet the CRZ standards, while allowing safe and convenient access by field personnel. Locating the cabinets between the entrance ramp and freeway mainline is generally undesirable. The cabinet should be located where the signal faces can be easily observed when work is being performed inside the cabinet. Specifically, position the access door to the cabinet so that when the door is open, field personnel can see the metering signal indications. Avoid placing cabinets on slopes 3:1 or steeper, behind sound walls or other similar types of structures, or areas subject to water runoff. Refer to the CA MUTCD and Caltrans Standard Plans for further location and installation details. See section 1.10 Enforcement Areas and Maintenance Vehicle Pullouts for additional cabinet placement requirements. Refer to Deputy Directive DD-113 and to Caltrans wire theft prevention guidelines for cabinet security.

*The exact number and location of controller cabinets requires the review and concurrence of the*

*Caltrans District Traffic Operations Branch responsible for ramp metering.*

## 2.5 Communications

A communication system is necessary between the ramp metering controller and a central control system located at the TMC. The communication system enables real-time data acquisition as well as central control from the TMC. Fiber-optic, microwave, radio frequencies, telephone landlines, and leased wireless systems are all possible choices for the communication system. Fiber-optic is the preferred choice of communication because of its capability to handle large amounts of data with high transmission speed. However, at locations where fiber-optic communication is not available or too costly, telephone service (wireless or landline) may be proposed.

*When wireless communication is proposed, the choice of integrated wireless communications equipment requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for electrical systems.*

When using analog, leased, landline phone service, install one telephone demarcation cabinet per telephone service point. If more than one entrance ramp will be metered, a telephone bridge should be installed in the ramp meter controller cabinet which is closest to the telephone demarcation cabinet.

*The telephone service requirements and the exact location requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for electrical systems, in coordination with the affected specific telephone provider involved.*

*When installing network equipment for Internet protocol (IP) addressable controllers, the connections to fiber network and integration with the TMC network requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for electrical systems. Network security requires that all field elements communicate with the central system via a transmission control protocol (TCP) /IP connection.*

To enable coordinated control between ramp meters and the upstream feeding arterial traffic signals, a communication conduit may be constructed between

the ramp metering controller cabinet and the nearest upstream arterial traffic signal controller cabinet.

## 2.6 Advance Warning Devices

Advance warning devices shall be installed at metered entrance ramps and connectors to alert approaching motorists when ramp meters are in operation.

See Chapter 3 Signing and Pavement Markings.

For entrance ramps with high approaching speeds, use the same type and layout of advance warning devices as those for connectors.

### 2.6.1 Advance Warning Devices for Metered Entrance Ramps

To alert approaching motorists when ramp meters are in operation, two advance warning devices are typically used at a metered entrance ramp. The first one, referred to as AW-I for short, is the "RAMP METER WHEN FLASHING" (W3-8) warning sign, as described in the CA MUTCD, with an amber colored flashing beacon on top. The beacon flashes whenever the downstream ramp control signal is in operation. The other device, referred to as AW-II for short, is the "RAMP METER AHEAD" (W3-7) warning sign with an amber-colored flashing beacon on top. The beacon flashes whenever the downstream ramp control signal is in operation. See Figure 2-12 for the installation details of the two advance warning devices.

At the entrance to a metered entrance ramp, at least one advance warning device, typically the AW-I, should be positioned facing each direction of traffic entering the ramp. Additional AW-I devices may be deployed further upstream of the ramp entrance to facilitate route diversion. Additional AW-II devices may also be provided at any location between the entrance and the limit line to alert approaching motorists of the presence of downstream metering signals or the presence of ramp metering traffic queue. Refer to CA MUTCD for additional sign design and placement guidance.

*The type and number of advance warning devices require the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering.*

The AW-I device is either roadside-mounted or overhead-mounted but is typically roadside-mounted. At a multi-lane entrance ramp, roadside-mounted advance warning devices shall be installed on both sides of the entrance ramp.

### 2.6.2 Advance Warning Devices for Metered Freeway-to-Freeway Connectors

On metered freeway-to-freeway connectors, high visibility activated blank-out (ABO) signs shall be installed for advance warning purposes.

At metered freeway-to-freeway connectors or other high-speed facilities, activated blank-out (ABO) signs or Extinguishable Message Signs (EMS) shall be used for advance warning purposes. "METER ON" and "PREPARE TO STOP" are the two standard advance warning messages, and respectively referred as AW-III and AW-IV for short.

The AW-III device is installed upstream of the entrance to a metered connector, alongside the freeway. It should be located a minimum 500 feet upstream of the gore point to provide sufficient distance, as shown in Figure 2-13, for the motorists on the freeway to decide whether to enter the metered connector or to take different routes. To convey a clearer message to the motorists, the "METER ON" message may include the name and direction of the metered connector. For example, as shown in Figure 2-13, "210 WEST METER ON" indicates that the connector to westbound Route 210 is metered. Additional AW-III devices may be deployed further upstream on the freeway mainline.

The AW-IV device should be installed at the entrance to the metered connector about 100 feet downstream of the 23-foot separation point of the exit gore area. The AW-IV device alerts the motorists of the possible presence of a ramp metering traffic queue. Additional AW-IV or AW-II devices may be deployed further downstream of the connector. The minimum spacing between the last advance warning device and the limit line should be the maximum queue length expected plus the stopping sight distance for the approach speed of the connector, but not less than 1,000 feet. See HDM Topic 201 for sight distance calculations.

The AW-III and AW-IV devices may be either overhead-mounted or roadside-mounted. At multi-lane entrance ramps, install roadside-mounted advance warning devices on both sides of the ramp. The operation of advance warning devices must be coordinated with metering operations. Terminate ramp metering operations once the upstream advance warning devices fail to function properly.

*Supporting structures other than those shown in the Caltrans latest Standard Plans require the review and approval by Caltrans Division of Engineering Services. The exact placement of the advance warning devices requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering.*

## **2.7 System Integration**

Newly-activated ramp metering locations should be added to the ramp metering central system database.

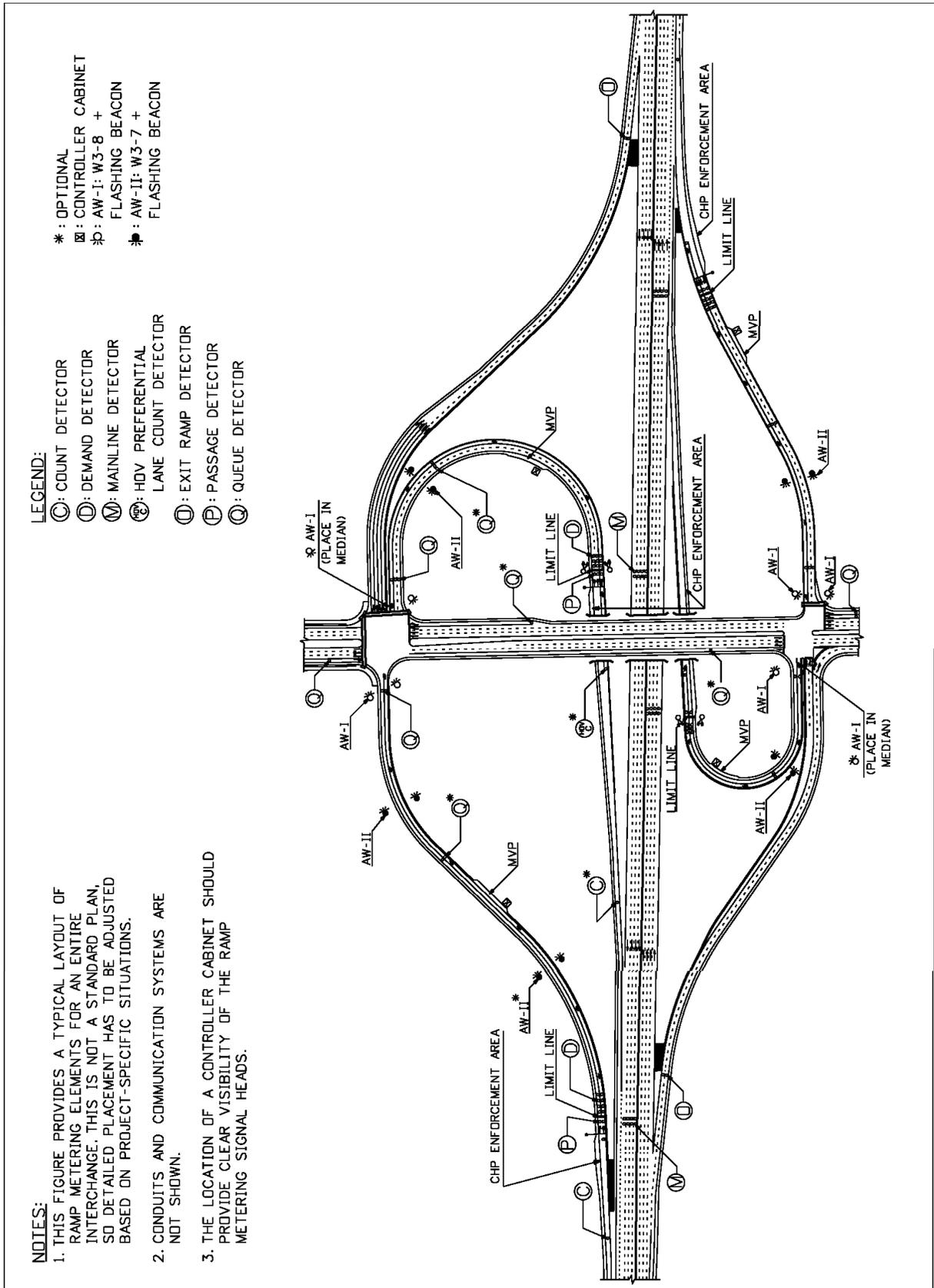
Real-time data acquisition from the new locations should be scheduled and integrated into the user interface/map display of the central system located in the TMC.

## **2.8 Temporary Entrance Ramp Meters**

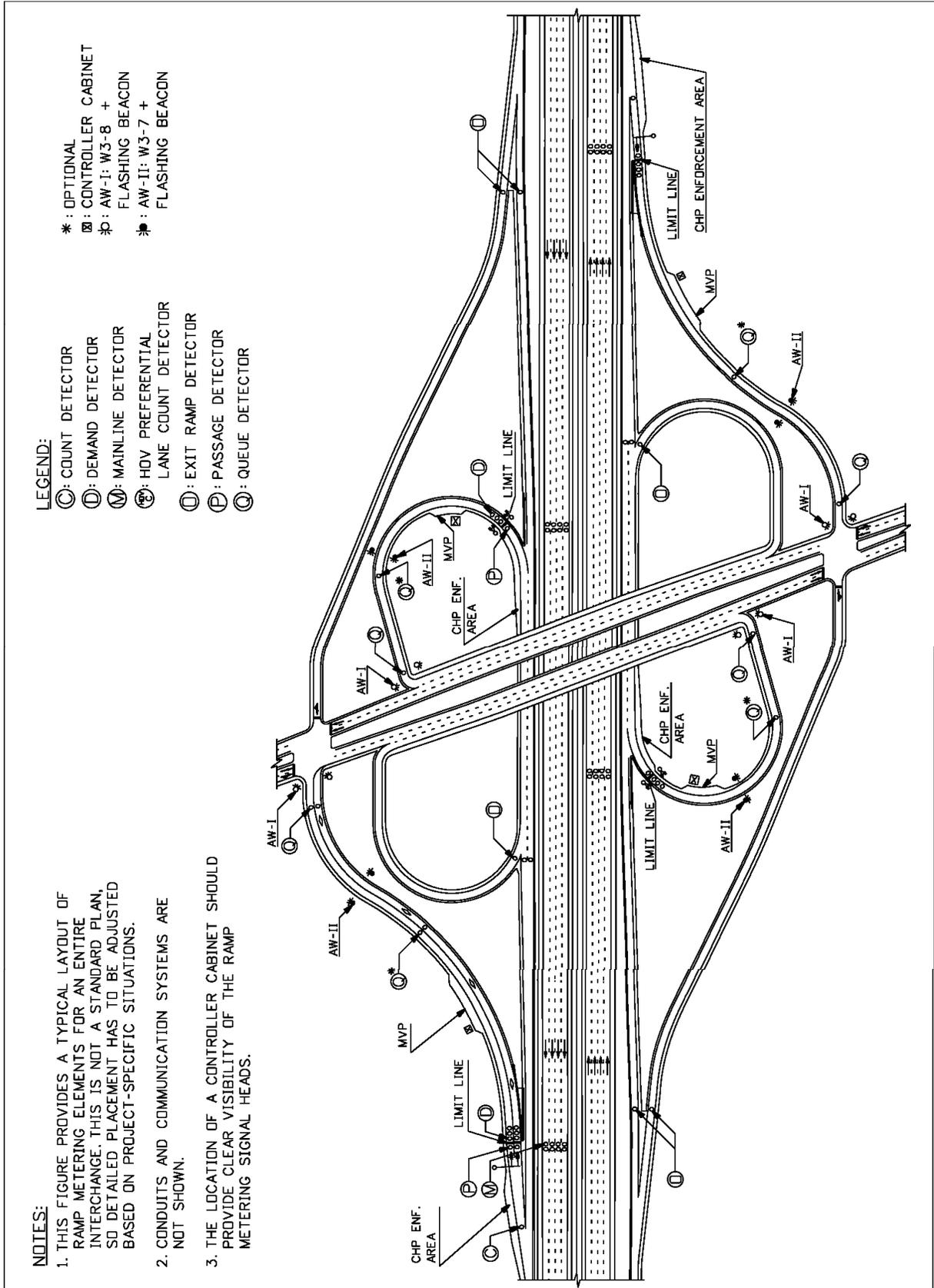
Temporary entrance ramp meters may be used, especially for traffic control during construction or special events. The temporary meters may be pre-timed traffic signals or ramp meters installed with partial hardware. However, their usage must satisfy all relevant Caltrans standards, guidelines, and specifications.

*The use of temporary entrance ramp meter requires the review and concurrence of the Caltrans District Traffic Operations Branch responsible for ramp metering.*

**Figure 2-1**  
**Typical Layout of Ramp Metering Elements at an L-9 Interchange**



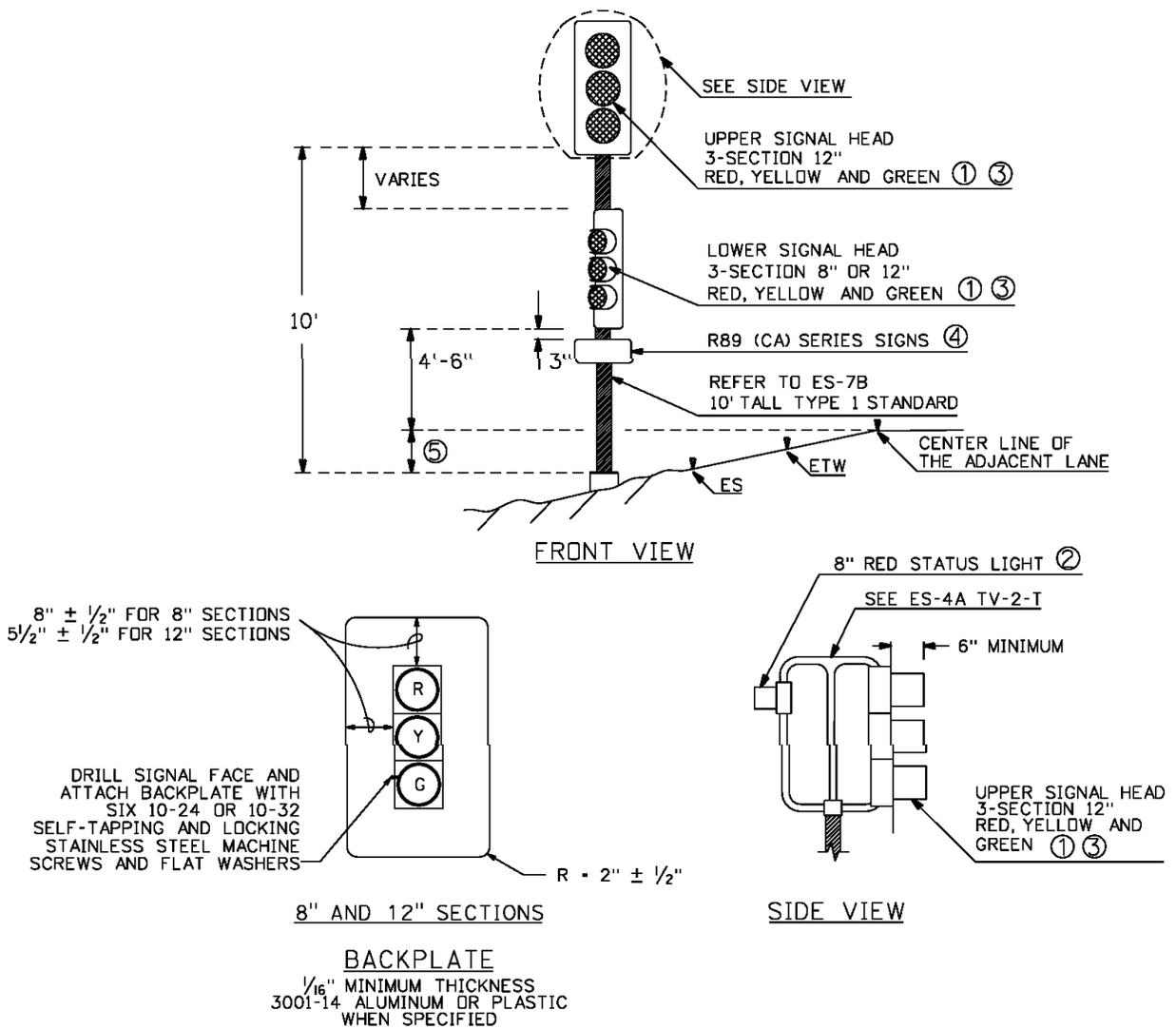
**Figure 2-2**  
**Typical Layout of Ramp Metering Elements at a Full-Cloverleaf Interchange**



**Figure 2-3**  
**Typical Type 1 Signal Standard Installations**

**NOTES:**

1. FOR ROADSIDE MOUNTED SIGNALS, THE UPPER HEAD SHOULD BE ADJUSTED TO FACE THE APPROACHING TRAFFIC; WHILE THE LOWER HEAD TO FACE THE STOPPED TRAFFIC AT THE LIMIT LINE.
2. PROVIDE A RED STATUS LIGHT ON THE BACKSIDE OF EACH METERING SIGNAL HEAD WITH INDICATION FACING THE CHP ENFORCEMENT AREA.
3. USE PROGRAMMED VISIBILITY HEADS. STANDARD HEADS MAY BE USED ON HIGH SPEED APPROACHES WHERE SIGHT DISTANCE IS LIMITED.
4. CONSIDER USING A SEPARATE POLE WHEN THE R89 (CA) SERIES SIGN IS BLOCKED BY CONCRETE BARRIERS OR OTHER OBSTRUCTIONS.
5. VARIES WITH CROSS SLOPE OF THE ROADWAY AND SHOULDER.



**Figure 2-4**  
**Typical Mast Arm Signal Standard Installations**

**NOTES:**

1. PROVIDE ONE SIGNAL HEAD FOR EACH METERED LANE. THE SIGNAL HEAD SHOULD BE CENTERED OVER THE CONTROLLED LANE.
2. PROVIDE A RED STATUS LIGHT ON THE BACKSIDE OF EACH METERING SIGNAL HEAD, WITH INDICATION FACING THE CHP ENFORCEMENT AREA.
3. ACQUIRE HEADQUARTER STRUCTURAL UNIT APPROVAL WHEN DEVIATING FROM STANDARD PLANS ES-7C TO ES-7H.
4. USE PROGRAMMED VISIBILITY HEADS. STANDARD HEADS MAY BE USED ON HIGH SPEED APPROACHES WHERE SIGHT DISTANCE IS LIMITED.
5. FOLLOW THE CLEAR RECOVERY ZONE REQUIREMENTS AS SPECIFIED IN HDM INDEX 309.1.

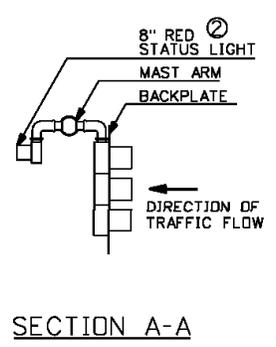
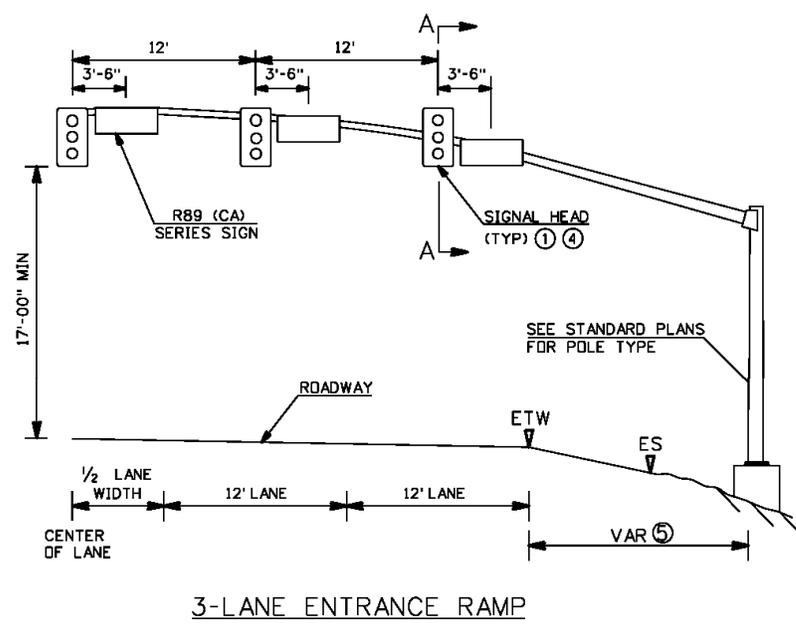
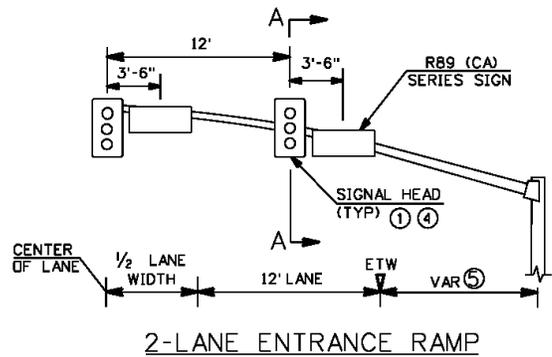
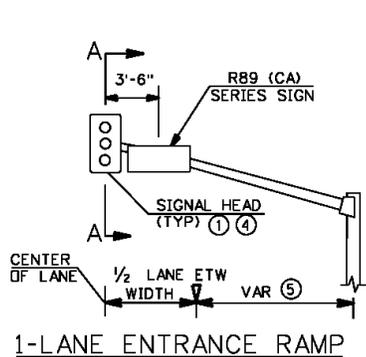


Figure 2-5  
Typical Signal Standard Placement Detail at Loop Entrance Ramps

**NOTES:**

1. DEVIATION FROM THE HOV PREFERENTIAL LANE POLICY REQUIRES THE PREPARATION OF AN EXCEPTION(S) TO RAMP METERING POLICY FACT SHEET, WHICH MUST BE CONCURRED WITH BY THE CALTRANS HQ TRAFFIC OPERATIONS LIAISON OR THE DESIGNATED REPRESENTATIVE AND APPROVED BY DEPUTY DISTRICT DIRECTOR OF TRAFFIC OPERATIONS.

2. A LOOP ENTRANCE RAMP INCLUDES ALL TYPES OF RAMPS WITH LIMITED SIGHT DISTANCE TO THE METERING SIGNALS.

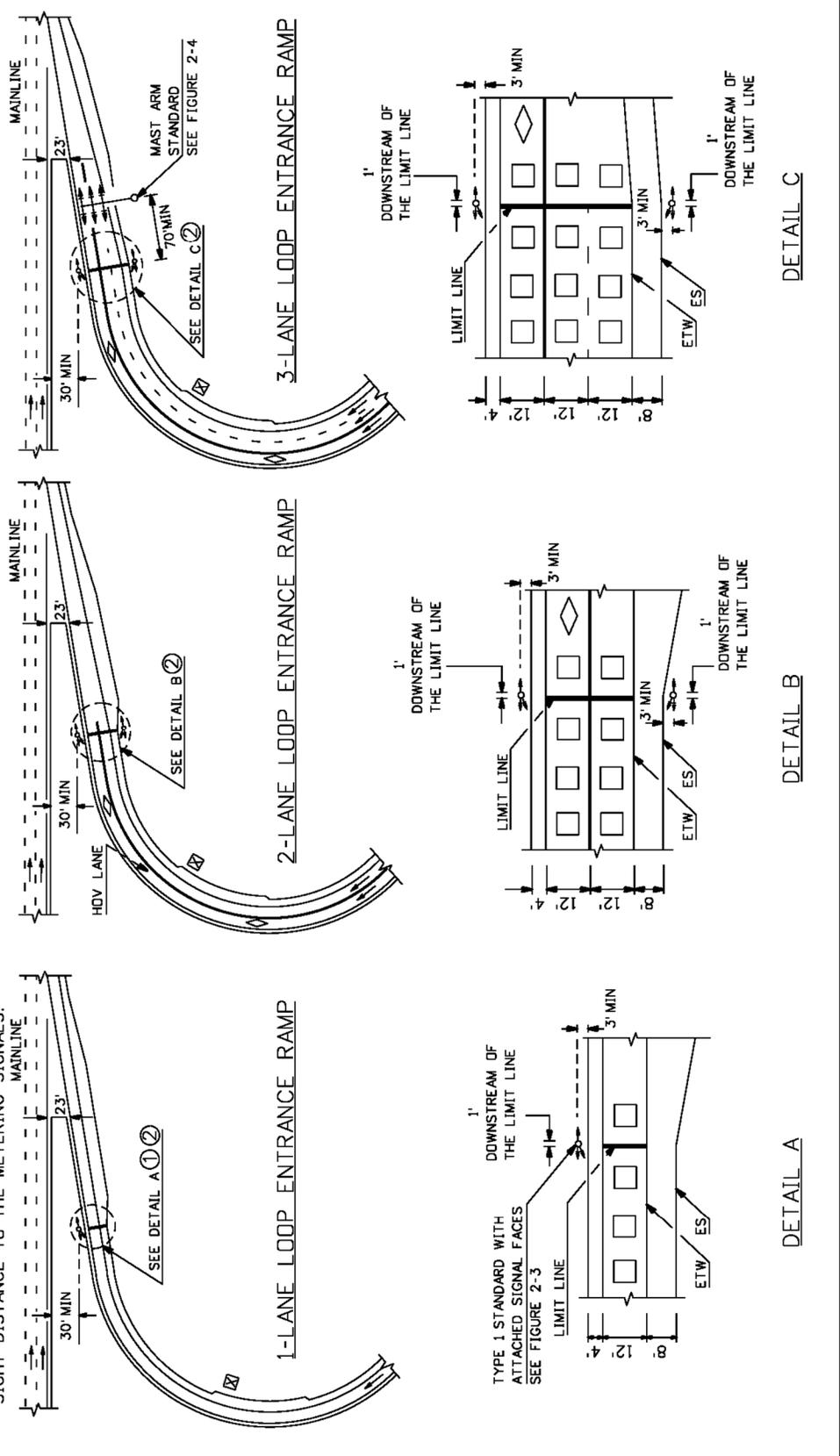
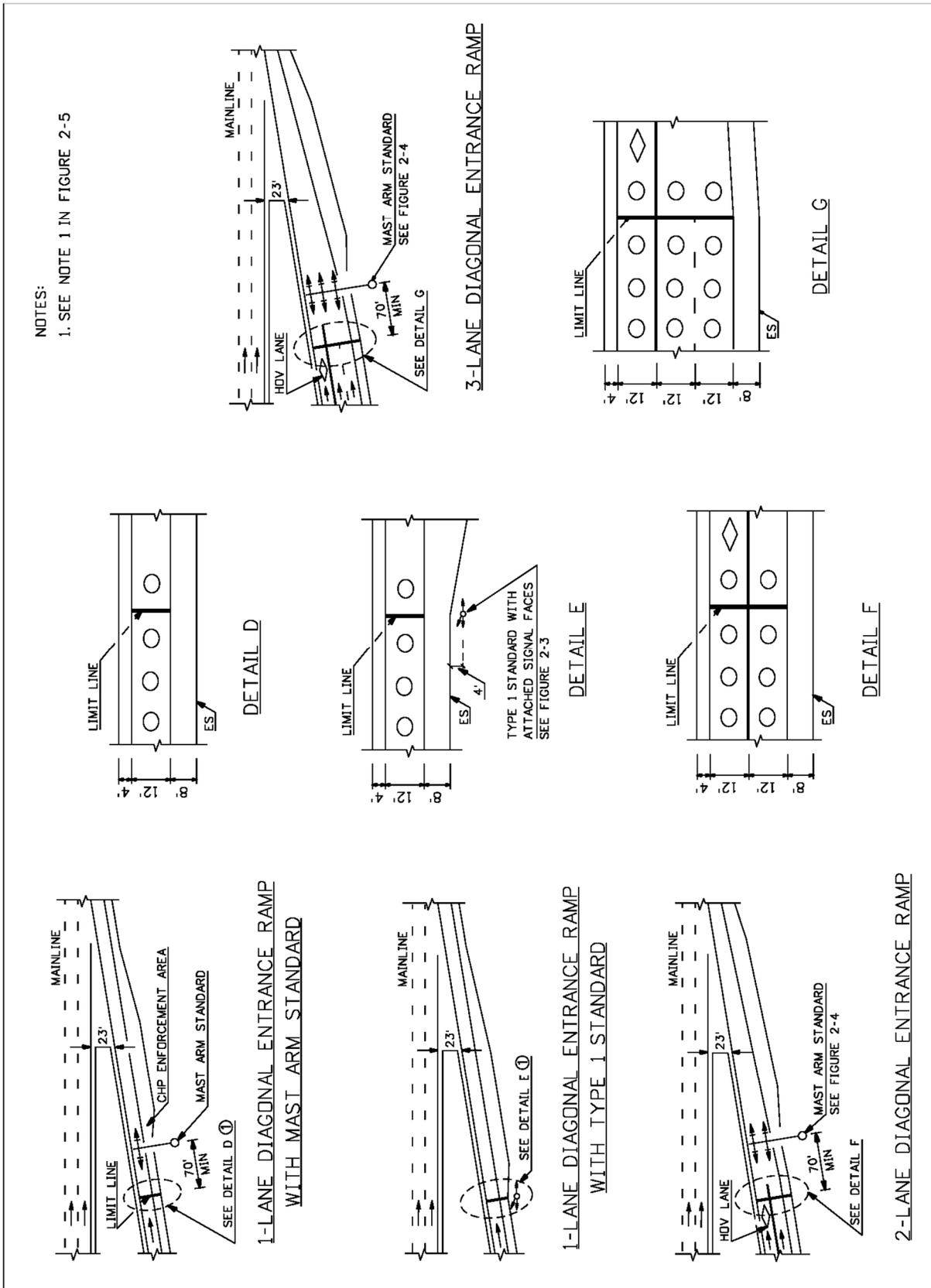


Figure 2-6

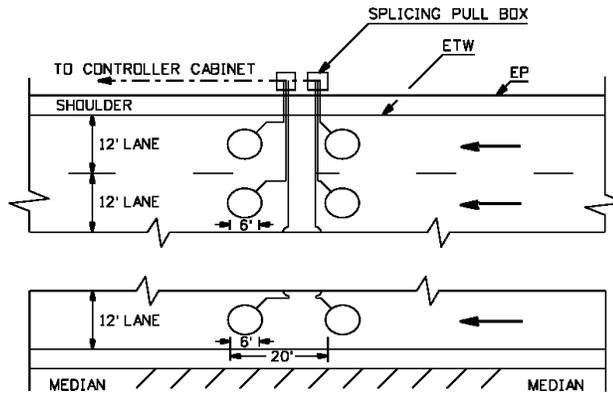
Typical Signal Standard Placement Detail at Diagonal Entrance Ramps



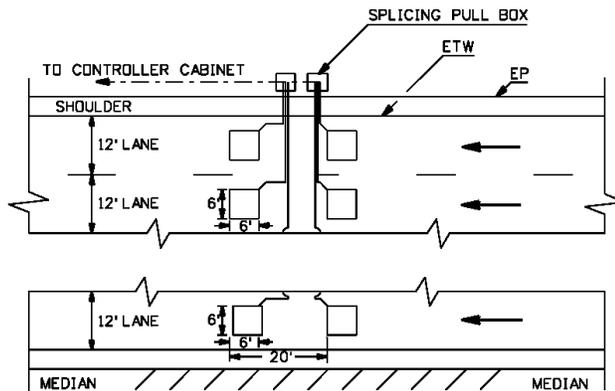
**Figure 2-7**  
**Typical Detector Layout for Freeway Mainline**

NOTES:

1. DETECTOR LOOPS MAY BE EITHER TYPE A OR TYPE E CENTERED IN EACH LANE. USE ONLY ONE TYPE OF LOOP AT EACH DETECTOR STATION.
2. SEE STANDARD PLANS ES-1C, ES-5A, ES-5B, AND ES-13A FOR LOOP CONFIGURATION AND INSTALLATION PROCEDURES.
3. SEE RMDM SECTION 2.3.2 FOR PLACEMENT OF MAINLINE LOOP DETECTORS.
4. LOCATE THE SPLICING PULL BOX ON THE RIGHT SIDE OF THE HIGHWAY FOR EASY MAINTENANCE.



TYPE E MAINLINE LOOP DETECTORS



TYPE A MAINLINE LOOP DETECTORS

**Figure 2-8**  
**Typical Detector Layout for a Two-Lane Entrance Ramp**

**NOTES:**

1. THE DETECTOR LOOPS MAY BE EITHER TYPE A OR TYPE E CENTERED IN EACH LANE. USE ONLY ONE TYPE OF LOOP AT EACH DETECTOR STATION.
2. SEE STANDARD PLANS ES-1C, ES-5A, ES-5B, AND ES-13A FOR LOOP CONFIGURATION AND INSTALLATION PROCEDURES.
3. LOCATE QUEUE DETECTORS AT THE ENTRANCE OF AN ENTRANCE RAMP. ADDITIONAL QUEUE DETECTORS MAY BE PROVIDED FURTHER UPSTREAM AND DOWNSTREAM OF THESE DETECTORS. LOCATION MUST BE REVIEWED BY THE CALTRANS DISTRICT TRAFFIC OPERATIONS BRANCH RESPONSIBLE FOR RAMP METERING.
4. CONSIDER MAINTENANCE SAFETY AND CONVENIENCE WHEN LOCATING THE CONTROLLER CABINET.

**LEGEND:**

- C OR ○ C : TYPE A OR TYPE E COUNT DETECTOR
- D OR ○ D : TYPE A OR TYPE E DEMAND DETECTOR
- P OR ○ P : TYPE A OR TYPE E PASSAGE DETECTOR
- Q OR ○ Q : TYPE A OR TYPE E QUEUE DETECTOR
- HOV C OR ○ HOV C : TYPE A OR E HOV PREFERENTIAL LANE COUNT DETECTOR
- EC : 6-FT SEPARATION POINT
- \* : OPTIONAL

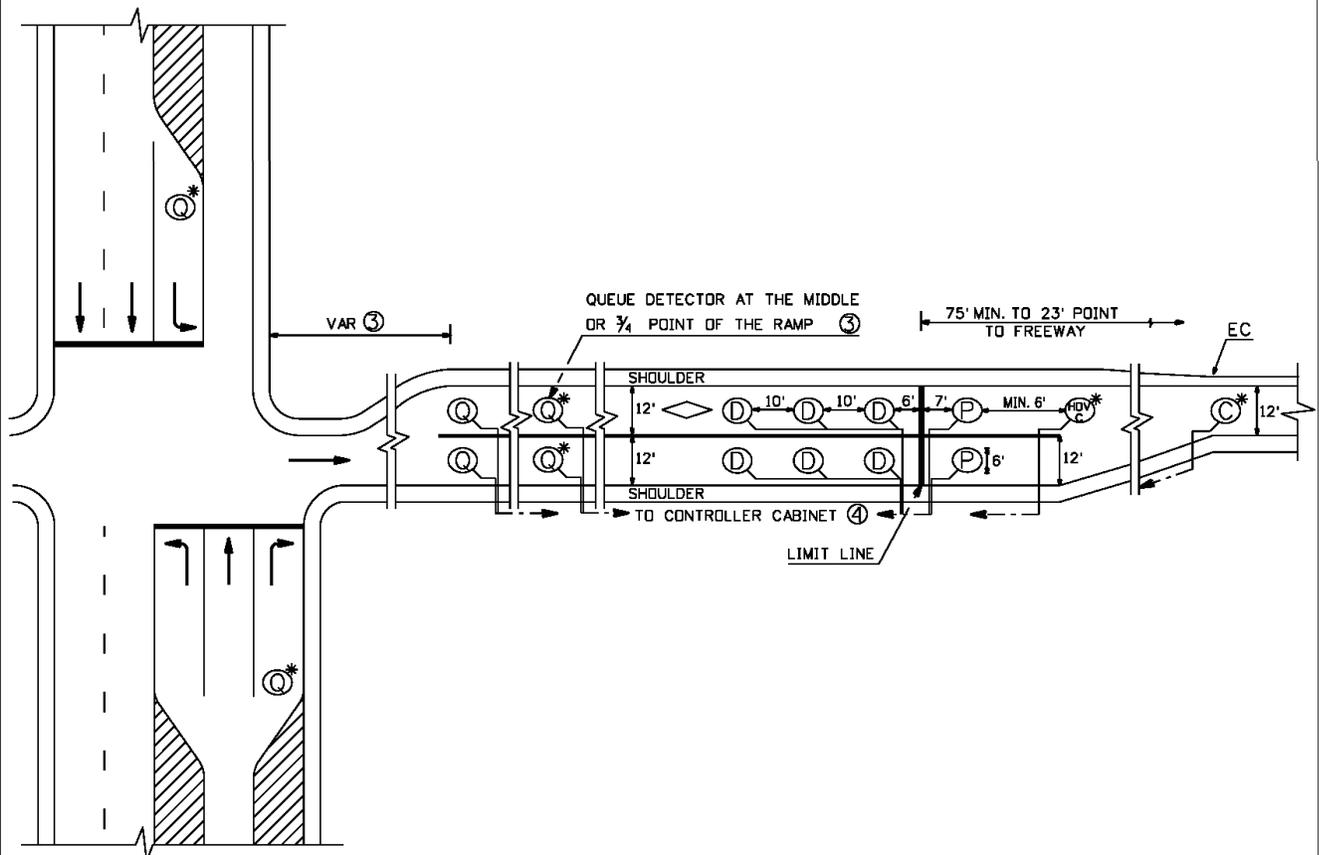


Figure 2-9

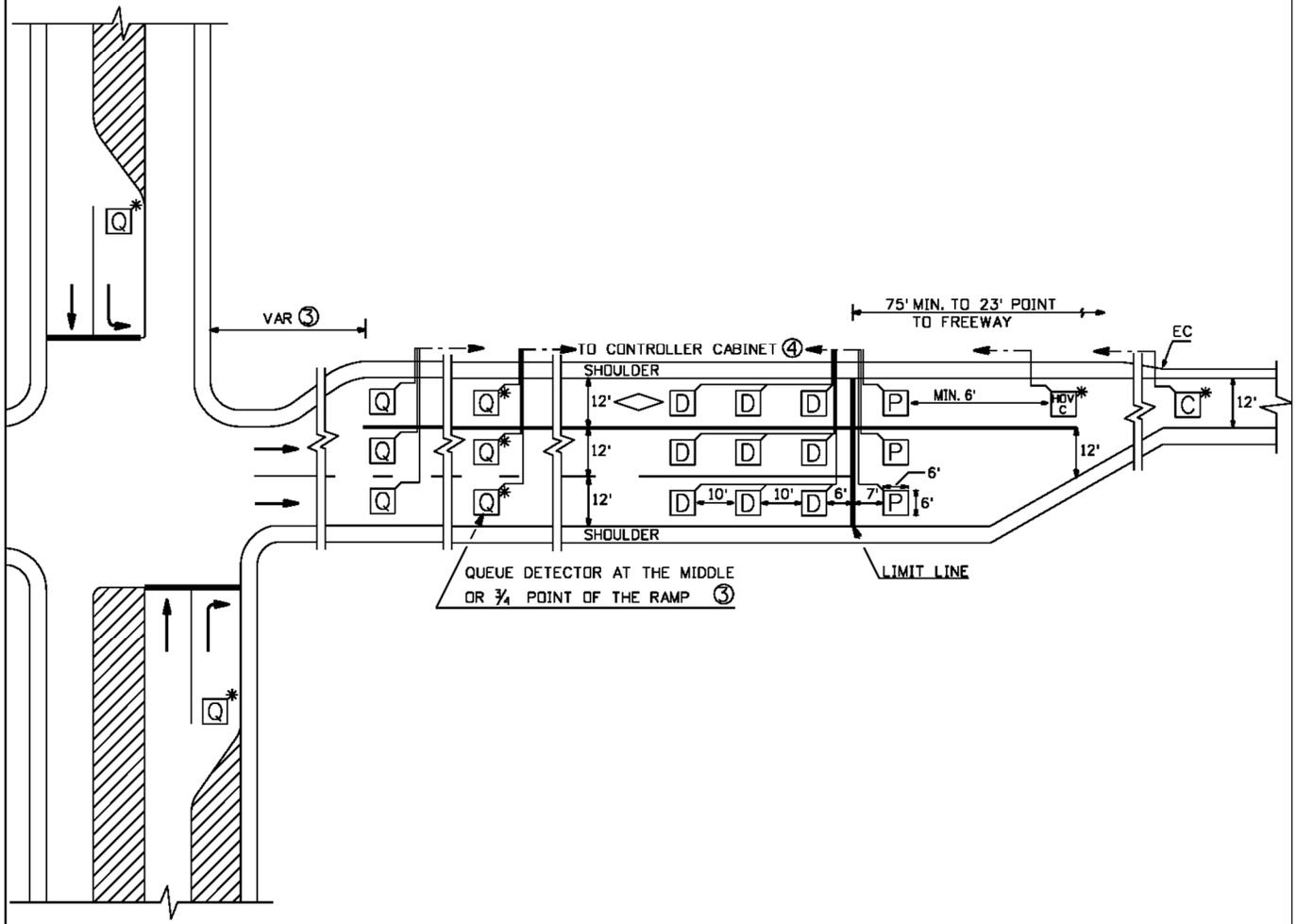
Typical Detector Layout for a Three-Lane Entrance Ramp

NOTES:

1. THE DETECTOR LOOPS MAY BE EITHER TYPE A OR TYPE E OR TYPE E CENTERED IN EACH LANE. USE ONLY ONE TYPE OF LOOP AT EACH DETECTOR STATION.
2. SEE STANDARD PLANS ES-1C, ES-5A, ES-5B, AND ES-13A FOR LOOP CONFIGURATION AND INSTALLATION PROCEDURES.
3. LOCATE QUEUE DETECTORS AT THE ENTRANCE OF AN ENTRANCE RAMP. ADDITIONAL QUEUE DETECTORS MAY BE PROVIDED FURTHER UPSTREAM AND DOWNSTREAM. LOCATION MUST BE REVIEWED BY CALTRANS DISTRICT TRAFFIC OPERATIONS BRANCH RESPONSIBLE FOR RAMP METERING.
4. CONSIDER MAINTENANCE SAFETY AND CONVENIENCE WHEN LOCATING THE CONTROLLER CABINET.

LEGEND:

- $\square$  C OR  $\odot$  C : TYPE A OR TYPE E COUNT DETECTOR
- $\square$  D OR  $\odot$  D : TYPE A OR TYPE E DEMAND DETECTOR
- $\square$  P OR  $\odot$  P : TYPE A OR TYPE E PASSAGE DETECTOR
- $\square$  Q OR  $\odot$  Q : TYPE A OR TYPE E QUEUE DETECTOR
- $\square$  HOV<sub>c</sub> OR  $\odot$  HOV<sub>c</sub> : TYPE A OR TYPE E HOV PREFERENTIAL LANE COUNT DETECTOR
- EC : 6-FT SEPARATION POINT
- \* : OPTIONAL



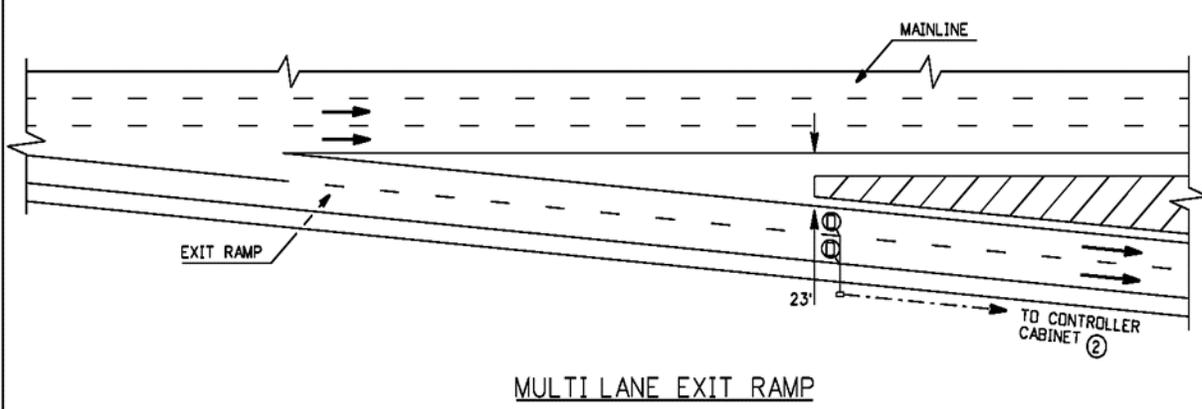
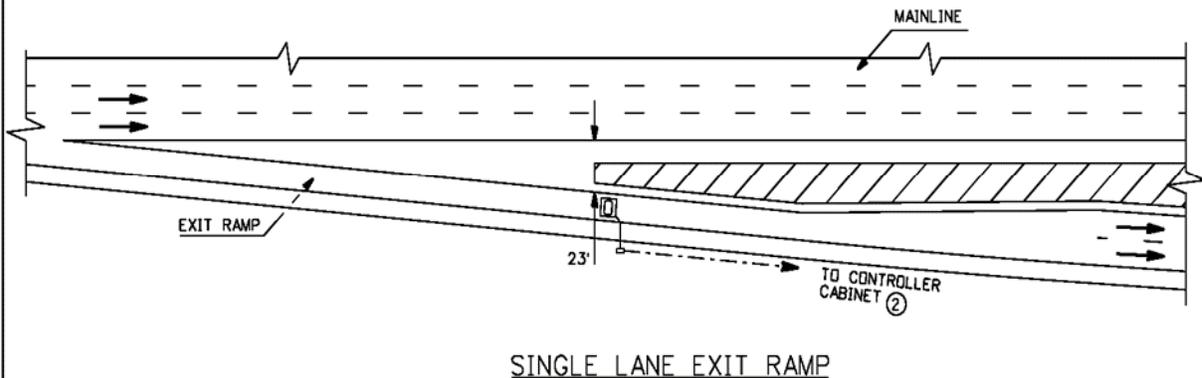
**Figure 2-10**  
**Typical Detector Layout for an Exit Ramp**

**NOTES:**

1. THE DETECTOR LOOPS MAY BE TYPE A OR TYPE E CENTERED IN EACH LANE. USE THE SAME TYPE OF LOOP AT EACH DETECTOR STATION.
2. SEE STANDARD PLANS ES-1C, ES-5A, ES-5B, AND ES-13A FOR LOOP CONFIGURATION AND INSTALLATION PROCEDURES.
3. PROVIDE EXIT RAMP DETECTOR(S) AT THE 23 FEET SEPARATION POINT CENTERED IN LANE.
4. CONNECT THE DETECTORS TO THE NEAREST APPROPRIATE CONTROLLER CABINET.

**LEGEND:**

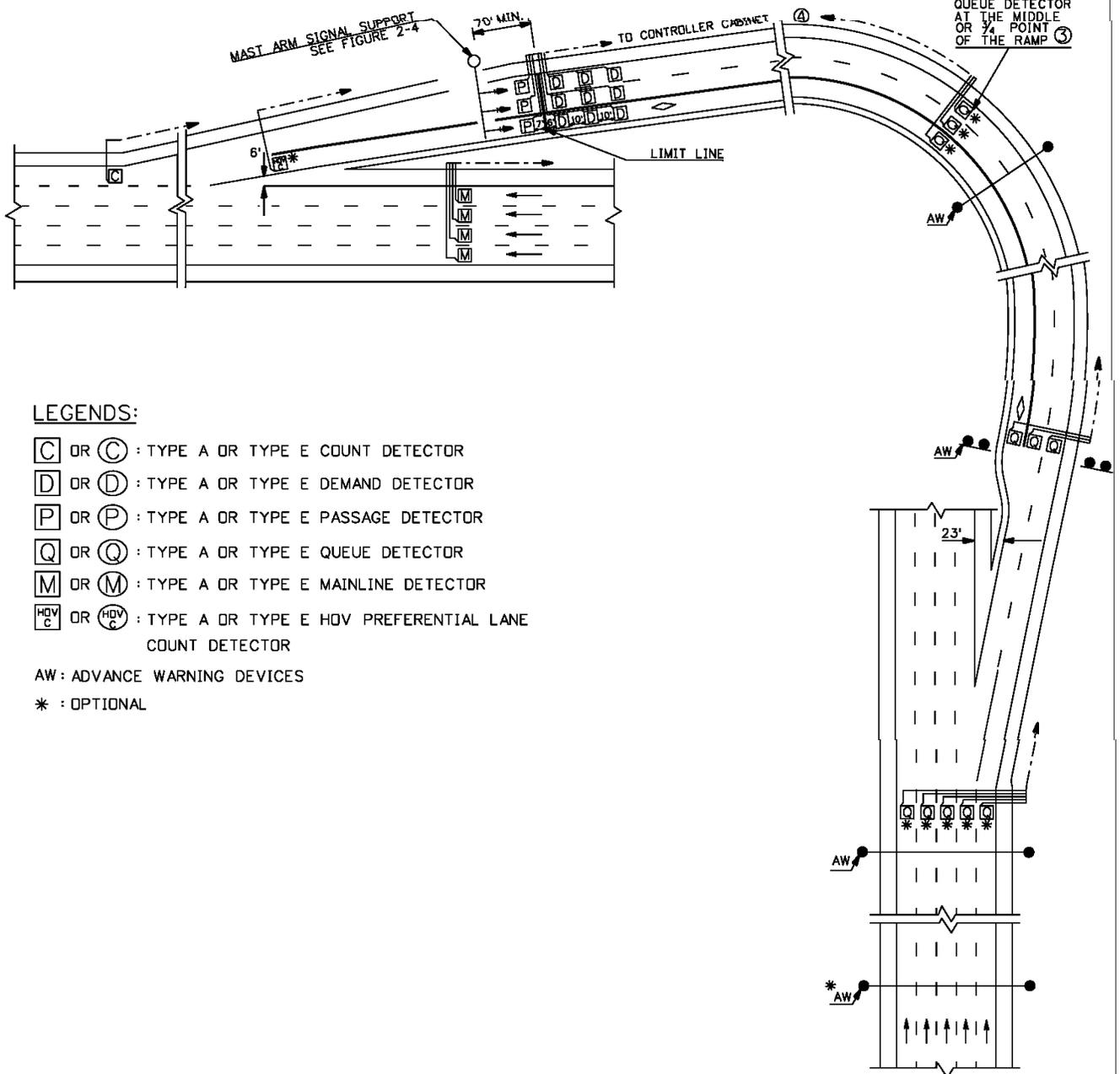
□ OR ⊙ : TYPE A OR TYPE E EXIT RAMP DETECTOR



**Figure 2-11**  
**Typical Detector Layout for a Metered Connector**

**NOTES:**

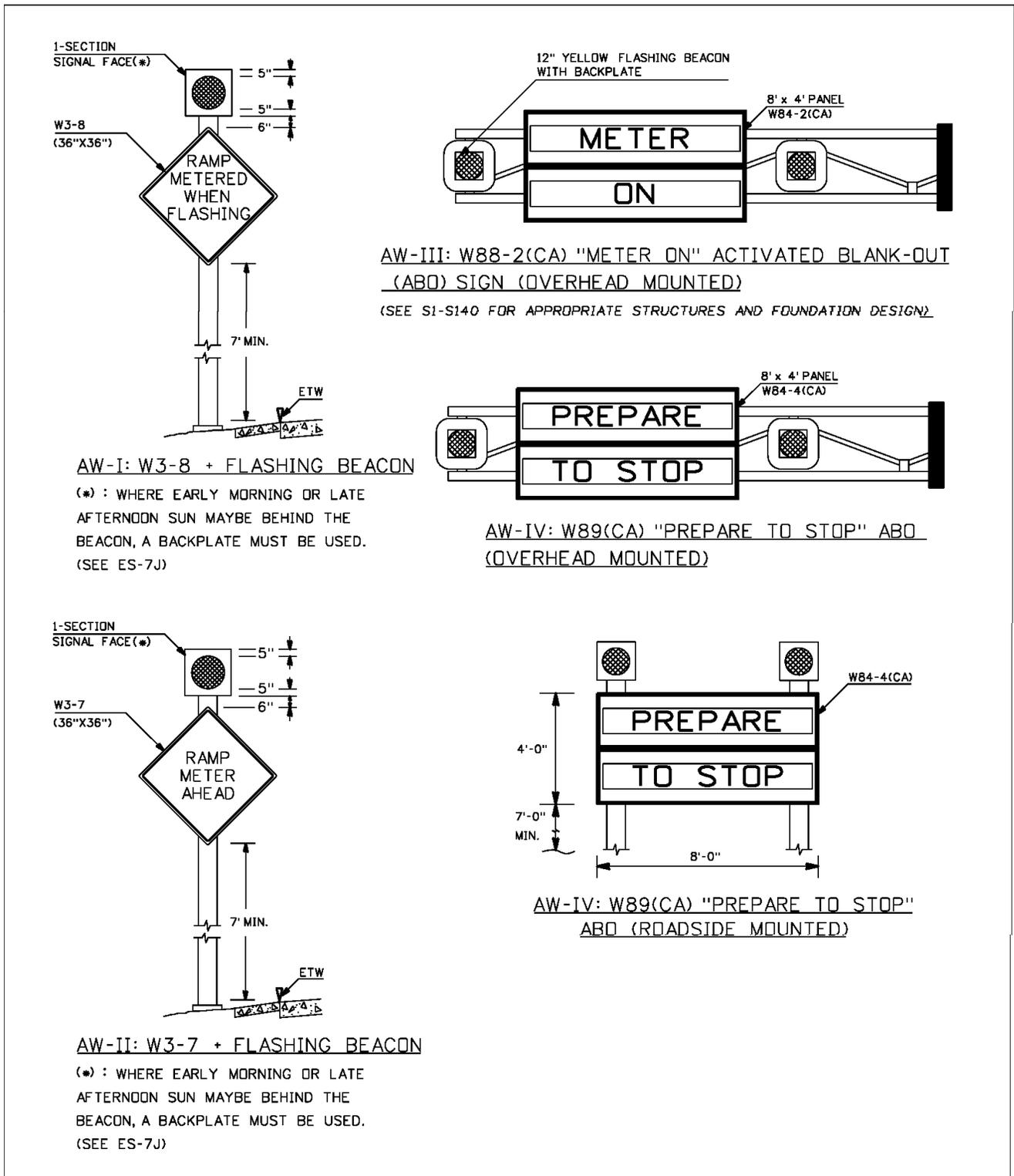
1. THE DETECTOR LOOPS MAY BE EITHER TYPE A OR TYPE E CENTERED IN EACH LANE. USE ONLY ONE TYPE OF LOOP AT EACH DETECTOR STATION.
2. SEE STANDARD PLANS ES-1C, ES-5A, ES-5B, AND ES-13A FOR LOOP CONFIGURATION AND INSTALLATION PROCEDURES.
3. LOCATE QUEUE DETECTORS AT THE ENTRANCE OF A CONNECTOR. ADDITIONAL QUEUE DETECTORS MAY BE PROVIDED. LOCATION MUST BE REVIEWED BY THE CALTRANS DISTRICT TRAFFIC OPERATIONS BRANCH RESPONSIBLE FOR RAMP METERING.
4. CONSIDER MAINTENANCE SAFETY AND CONVENIENCE WHEN LOCATING A CONTROLLER CABINET.



**LEGENDS:**

- OR ○ : TYPE A OR TYPE E COUNT DETECTOR
- OR ○ : TYPE A OR TYPE E DEMAND DETECTOR
- OR ○ : TYPE A OR TYPE E PASSAGE DETECTOR
- OR ○ : TYPE A OR TYPE E QUEUE DETECTOR
- OR ○ : TYPE A OR TYPE E MAINLINE DETECTOR
- OR ○ : TYPE A OR TYPE E HOV PREFERENTIAL LANE COUNT DETECTOR
- AW : ADVANCE WARNING DEVICES
- \* : OPTIONAL

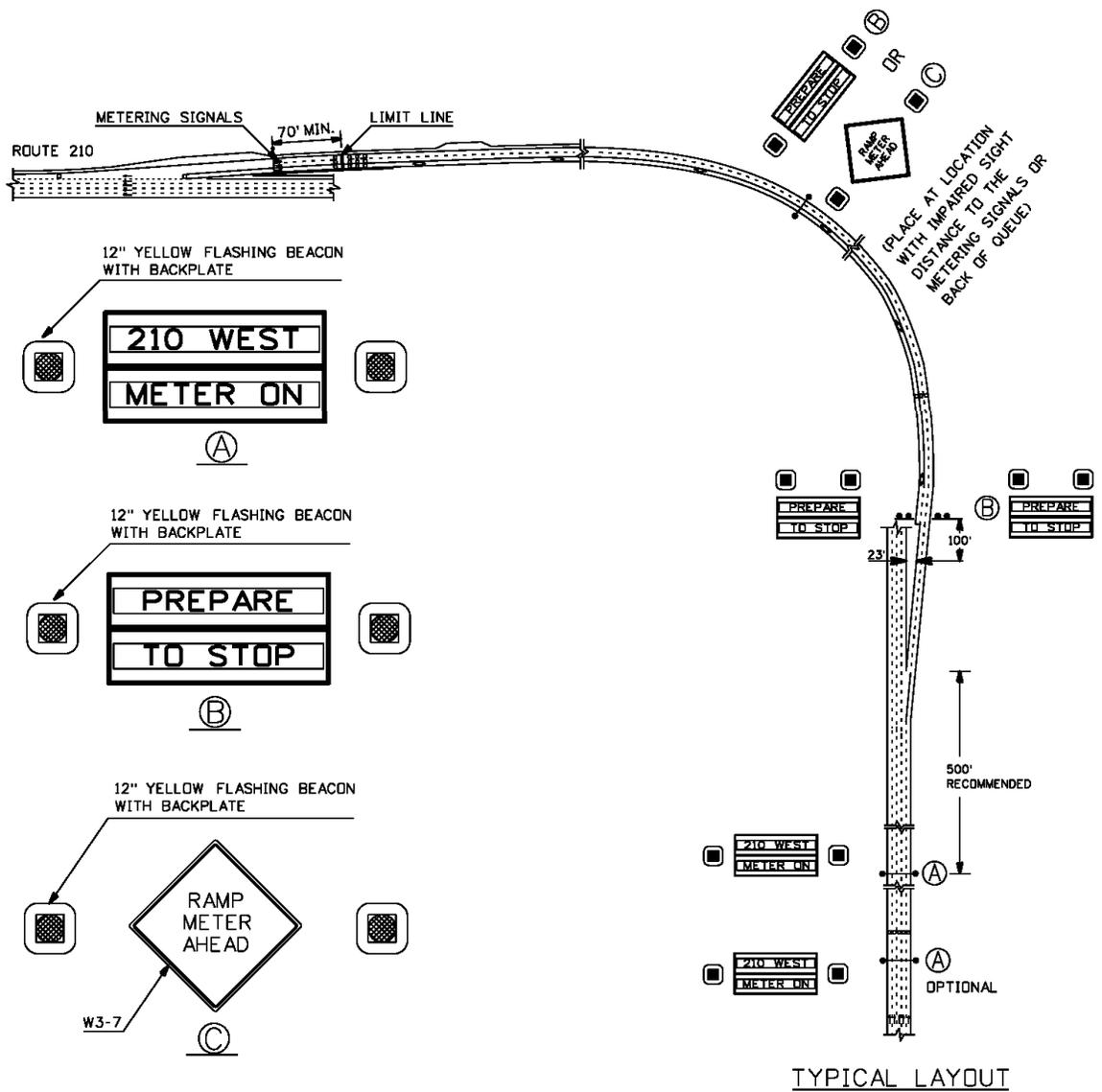
**Figure 2-12**  
**Typical Advance Warning Devices**



**Figure 2-13**  
**Typical Advance Warning Device Layout for a Metered Connector**

**NOTES:**

1. THE MINIMUM DISTANCE BETWEEN THE "PREPARE TO STOP" ACTIVATED BLANK-OUT (ABO) SIGN AND THE LIMIT LINE SHOULD BE THE MAXIMUM QUEUE LENGTH PLUS THE STOPPING SIGHT DISTANCE FOR THE APPROACH SPEED.
2. THE LOCATIONS OF THE ADVANCE WARNING DEVICES SHOULD BE REVIEWED BY THE CALTRANS DISTRICT TRAFFIC OPERATION BRANCH RESPONSIBLE FOR RAMP METERING.
3. ABO MAY BE ROADSIDE- OR OVERHEAD-MOUNTED. FOR MULTILANE CONNECTORS, THE ABO SHOULD BE PROVIDED ON BOTH SIDES OF THE CONNECTORS, IF ROADSIDE-MOUNTED.
4. ABO STRUCTURE SUPPORT PLACED WITHIN THE CLEAR RECOVERY ZONE MUST BE PROPERLY SHIELDED AS SPECIFIED IN HDM INDEX 309.1.



## CHAPTER 3 SIGNING AND PAVEMENT MARKINGS

### 3.1 General Standards

All signs and pavement markings for metered entrance ramps shall conform to the CA MUTCD, Caltrans Standard Specifications, Caltrans Standard Plans, and the HDM.

*Exceptions to the aforementioned publications and proposed evaluation of other signs and markings requires the review and concurrence of Caltrans Headquarters Traffic Operations, Office of Traffic Engineering.*

*The number, size, and location of signs and pavement markings require the review and concurrence of Caltrans District Traffic Operations Branch responsible for ramp metering.*

### 3.2 Signing

#### 3.2.1 Vehicle(s) per Green Signs

As shown in Table 3-1, the R89 (CA), R89-1 (CA), and R89-2 (CA) signs are used to indicate the maximum number of vehicles allowed to proceed for each metering cycle.

When a Type 1 standard is used, attach one R89 (CA), R89-1 (CA), or R89-2 (CA) sign per standard, 3 inches below the lower signal head as shown in Figure 2-3, or between the upper and lower signal heads. The letter height should be at least 3 inches to provide better visibility for the stopped motorists. If visibility to the sign is obstructed, the sign may be attached to a separate post. Use a R89 (CA) sign for a single-lane metered entrance ramp. For a multi-lane metered entrance ramp, use an R89-1 (CA) sign for simultaneous release operations, and an R89-2 (CA) sign for staggered release operations. The R89-3 (CA) sign, as shown in Table 3-1, may be used at a multi-lane metered entrance ramp to indicate an individual signal head for each lane of traffic to reduce motorist confusion.

When a mast arm standard is used, provide one R89 (CA), R89-1 (CA), or R89-2 (CA) sign 3.5 feet (center-to-center) to the right of each signal head. A letter height of at least 4 inches should be used since

the sign is more than 70 feet away from the stopped vehicles.

Table 3-1 Regulatory Signs

Sign Designation	Sign Picture
R10-6	
R13A (CA)	
R13B (CA)	
R33 (CA)	
R33A (CA)	
R89 (CA)	
R89-1 (CA)	
R89-2 (CA)	
R89-3 (CA)	

#### 3.2.2 Stop Here on Red Signs

When a Type 1 standard is used, an R10-6 sign, as shown in Table 3-1, should be installed to indicate to the motorists where to stop. A separate sign post

may be used if the R10-6 sign does not fit between the lower and upper signal heads, or below the lower signal head.

When a mast-arm standard is used for a single-lane entrance ramp, install one R10-6 sign on the right side of the entrance ramp at the limit line to help direct the motorists where to stop. For a multi-lane entrance ramp, install one R10-6 sign on each side of the entrance ramp at the limit line on separate sign posts or on Type 1 standards. Each sign post shall be breakaway.

### 3.2.3 HOV Preferential Lane Signs

As shown in Table 3-2, the HOV preferential lane signs, such as R90-1 (CA), R91-1 (CA), and R94 (CA) are regulatory signs. These signs designate which lane(s) is limited to HOV preferential traffic, specify the occupancy (number of persons per vehicle) requirement, and indicate the hours when the occupancy requirement is in effect. In general, the vehicle occupancy requirement for an HOV preferential lane is two or more persons per vehicle.

Use the R91-1 (CA) sign to designate the HOV preferential lanes at metered entrance ramps or freeway-to-freeway connectors. When used, the R91-1 (CA) sign should be adjacent to an HOV diamond symbol pavement marking. The R91-1 (CA) sign should be installed at a minimum of two locations along the entrance ramp. See Figures 3-1 through 3-5 for the typical layout of the R91-1 (CA) signs at metered entrance ramps. See Figure 3-6 for the spacing of HOV diamond symbol pavement marking.

The HOV preferential lanes may operate on a part-time or full-time basis. When an HOV preferential lane operates on a part-time basis, the message “WHEN METERED” is used at the bottom of the R91-1 (CA) sign as shown in Table 3-2. A part-time HOV preferential lane is open to all traffic outside the posted restriction hours. When an HOV preferential lane operates on a full-time basis, the message “24 HOURS” is used at the bottom of the R91-1 (CA) sign instead of “WHEN METERED.” A full-time HOV lane restricts access to only HOV traffic at all times.

Other HOV preferential lane signs, such as the R90-1 (CA) sign shown in Table 3-2 should be placed when converting an existing non-metered HOV preferential lane to a metered operation. It may also

be used on new metering installations where all lanes, including the HOV preferential lane, would be metered to prevent motorist confusion. The R90-1 (CA) sign shall be installed upstream of the limit line on the same side as the HOV preferential lane.

**Table 3-2 HOV Regulatory Signs**

Sign Designation	Sign Picture
R90-1 (CA)	
R91-1 (CA)	
R94 (CA)	
R33B (CA)	
R33C (CA)	

### 3.2.4 Movement Prohibition and Lane Control Signs

An HOV preferential lane must have clear signage to avoid trapping non-HOV traffic. To designate a dedicated turn-lane on a local roadway for HOV traffic, use the R94 (CA), R33B (CA), or R33C (CA) signs as shown in Table 3-2.

The R13A (CA) and R13B (CA) signs designate turning movement restrictions when no turn on red is permitted. The R33 (CA) and R33A (CA) signs designate turning movement restrictions only during specific time periods. The R13A (CA), R13B (CA), R33 (CA), and R33A (CA) signs are shown in Table 3-1. Refer to the CA MUTCD for additional sign designs and placement guidance.

*Obtain the concurrence of the local agencies and the Caltrans District Traffic Operations Branch responsible for signing and pavement markings before installing signs on local roadways.*

### 3.2.5 Advance Warning Signs

The "RAMP METER AHEAD" sign (W3-7) and "RAMP METER WHEN FLASHING" sign (W3-8), as shown in Table 3-3, are used to warn the presence of a downstream ramp metering signal. A flashing beacon on top of the sign post is necessary to indicate when the ramp metering is active. See section 2.6 Advance Warning Devices for the placement of these signs.

### 3.2.6 Lane Ends Warning Signs

The Lane Ends signs (W4-2L and W4-2R), as shown in Table 3-3, are used to warn of the reduction in the number of traffic lanes in the direction of travel on a multi-lane entrance ramp. Use the correct sign, W4-2L or W4-2R, to match the direction of lane-drop in the field. When used, the W4-2 signs should be located downstream of the limit line to warn motorists during the non-metered periods of the downstream lane-drop situation.

### 3.2.7 Activated Blank-Out Signs

Three activated blank-out signs are used for ramp metering advance warning devices. These signs are the W88-2 (CA), W88-3 (CA), and W89 (CA) as shown in Table 3-4. These signs are activated only when the ramp meters are in operation. See section 2.6 Advance Warning Devices for the placement of these signs.

**Table 3-3 Warning Signs**

Sign Designation	Sign Picture
W3-7	
W3-8	
W4-2L	
W4-2R	

**Table 3-4 Activated Blank-Out Signs**

Sign Designation	Sign Picture
W88-2 (CA)	
W88-3 (CA)	
W89 (CA)	

### 3.3 Pavement Markings

#### 3.3.1 General

Pavement markings at a metered entrance ramp include arrows, edge lines, lane lines, limit lines, and HOV diamond symbols. Raised pavement markers may be installed along the markings. Unless otherwise noted, pavement markings for a metered connector are the same as a metered entrance ramp. See Figures 3-1 to 3-5 for the typical layouts of pavement markings for various entrance ramp configurations.

#### 3.3.2 Type I Arrow

A minimum of one Type I arrow shall be placed in the center of each entrance ramp lane so that it is clearly viewable by the approaching motorists. The arrow shall not be less than 18 feet in length as specified in the CA MUTCD, Section 3B.20 Pavement Word, Symbol, and Arrow Markings.

#### 3.3.3 Limit Line

A limit line is a single 12-inch wide, white thermoplastic pavement marking placed transversely from edge of traveled way (ETW) to ETW across all metered entrance ramp lane(s), including the HOV preferential lane. Staggered limit lines shall not be used. The limit line may be illuminated as described in section 2.2.3 Limit Line Lighting.

#### 3.3.4 HOV Preferential Lane Symbols

The HOV preferential lane shall be marked with the standard HOV elongated diamond symbols spaced 128 feet apart as shown in Figure 3-6. The symbol should be placed adjacent to the R91-1 (CA) sign that designates the operating hours of the HOV preferential lane. A minimum of two symbols should be installed at each entrance ramp. One symbol must be placed within 30 feet of the limit line. The 128 feet spacing requirement should be maintained by adjusting the spacing between the symbol nearest to the limit line and the prior symbol immediately upstream.

The pavement word marking "HOV LANE" may be painted between the diamond symbols on new projects to supplement, but not substitute for, the diamond symbols. This pavement word marking is to be used for initial implementation and then allowed to wear out.

#### 3.3.5 Edge Lines and Lane Lines

Edge lines, or edge line pavement markings, are used to separate the travel lane from an adjacent shoulder. For the left edge line and pavement markers at a metered entrance ramp, use the CA MUTCD Detail 25A between the ramp entrance and the gore area, and then Detail 36A (for merging after the 6 feet separation point) or Detail 36B (for merging onto an auxiliary lane). For the right edge line, use the Detail 27B.

Lane lines, or lane line pavement markings, delineate the separation of traffic lanes that have the same direction of travel. For the lane line separating the HOV preferential lane and the GP lane(s), use Detail 43. As shown in Figure 3-6, to avoid trapping GP traffic into an HOV preferential lane, use Detail 40 to distinguish the bay taper from the GP lane(s). For the lane lines and pavement markers between the GP lanes, use Detail 9 or 10 when the approaching speed is 40 mph or less; and use Detail 12 or 13 when the approaching speed is higher than 45 mph. To discourage last-minute lane changes, use a Detail 27B lane line in place of the Detail 9, 10, 12, or 13 lane line from the limit line to a point 50 feet upstream of the limit line, as illustrated in Figures 3-1 to 3-5, and Figures 3-7 to 3-8.

#### 3.3.6 Pavement Markings at the Lane-Drop Transition Zone

Multi-lane entrance ramps typically taper down to a single lane at the merge with the freeway mainline. In general, the lane-dropping process takes place in the lane-drop transition zone and starts on the right side of the entrance ramp so that traffic merges to the left, until only the leftmost lane remains. As shown in Figure 3-7, the lane-drop transition zone typically begins at the limit line or some distance downstream of the limit line depending on entrance ramp geometry, and ends where the auxiliary lane, or merging taper begins. If the lane-drop transition zone starts some distance downstream of the limit line, all existing edge lines and lane lines carry on downstream until the starting point of the lane-drop transition zone. In the lane-drop transition zone, the edge lines and lane lines should be the same details as the immediate upstream segment. The lane lines will terminate at specified points according to the type and number of lanes on the entrance ramp.

For a two-lane metered entrance ramp, the lane line terminates at the starting point of the lane-drop

transition zone. For a three-lane metered entrance ramp with one HOV lane as the leftmost lane, as shown in Figure 3-7, the lane line between the HOV preferential lane and GP lane extends downstream of the starting point of the lane-drop transition zone, until the lateral distance between the left and right ETW is two lane widths. The lane line between the GP lanes terminates at the starting point of the lane-drop transition zone. For a three-lane entrance ramp without an HOV preferential lane, the lane line between the two left GP lanes extends downstream of the starting point of the lane-drop transition zone, until the lateral distance between the left and right Edge of Travel Way (ETW) is two lane widths. The lane line between the two right GP lanes terminates at the starting point of the lane-drop transition zone.

For a three-lane metered connector with an HOV lane as the leftmost lane, as shown in Figure 3-7, the lane line between the HOV preferential lane and GP lane extends downstream of the beginning of the first lane-drop transition zone, until the lateral distance between the left and right ETW is two lane widths. The lane line between the HOV preferential lane and GP lane extends further downstream for 300 feet using the CA MUTCD Detail 9, 10, 12, or 13. The lane line between the GP lanes terminates at the starting point of the second lane-drop transition zone.

For a three-lane metered connector without an HOV preferential lane, the lane line between the two left GP lanes extends downstream of the starting point of the lane-drop transition zone, and continues until the lateral distance between the left and right ETW is two lane widths. The lane line between the two right GP lanes terminates at the starting point of the lane-drop transition zone.

When an HOV preferential lane is on the right side of the entrance ramp, drop the HOV preferential lane before any GP lanes so traffic merges to the left. The lane line between the HOV preferential lane and GP lane ends at the starting point of the lane-drop transition zone, regardless of the total number of lanes. For a three-lane metered entrance ramp, as shown in Figure 3-8, the lane line between the two left GP lanes extends downstream until the lateral distance between the left and right ETW is two lane widths. For a three-lane metered connector, as shown in Figure 3-8, the lane line between the two left GP lanes extends downstream of the starting point of the lane-drop transition zone, and continues until the lateral distance between the left and right ETW is two lane widths.



Figure 3-2

Typical Signing and Pavement Marking

(2-Lane Entrance Ramp with Intersection/HOV Preferential Lane)

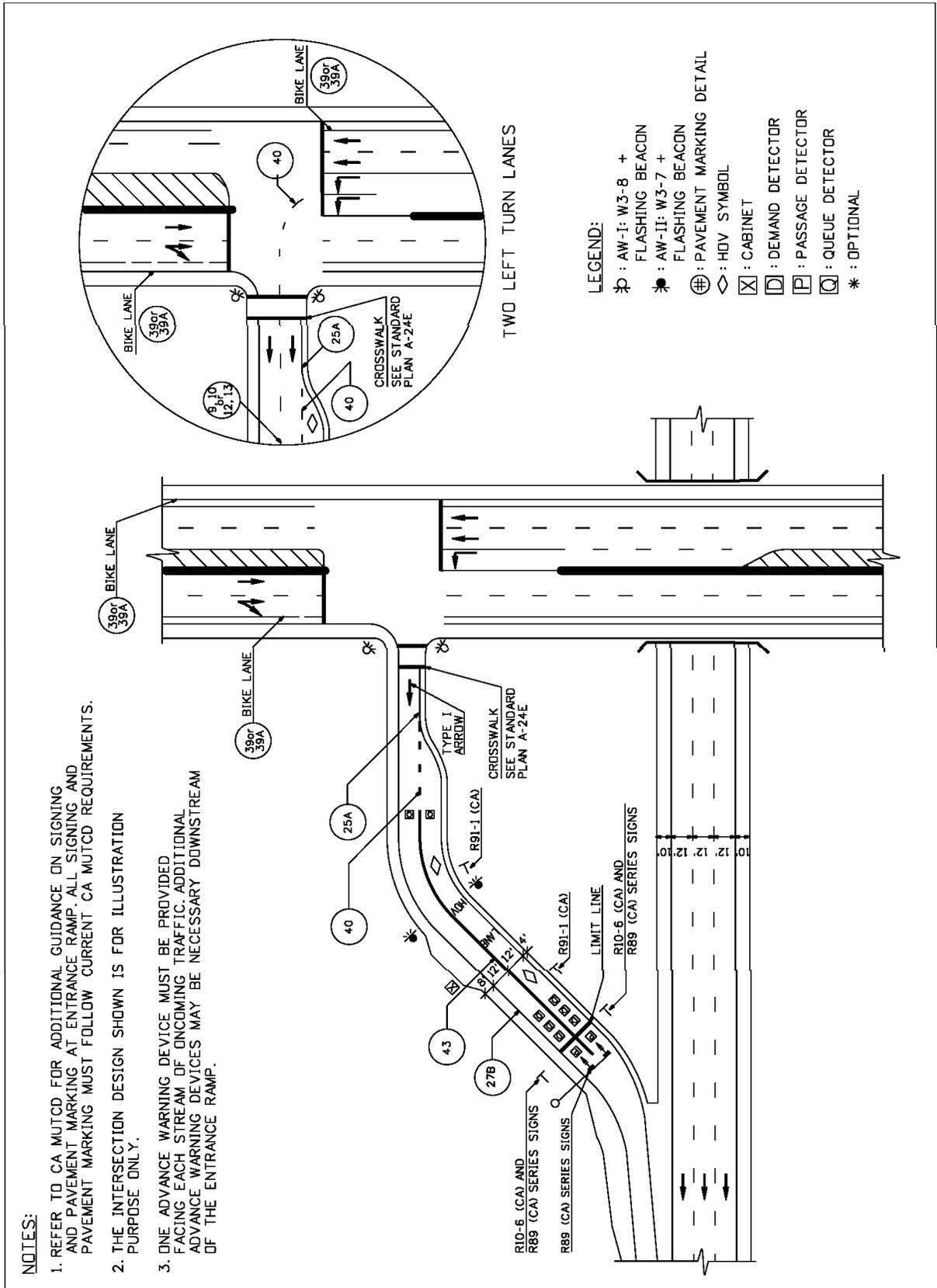
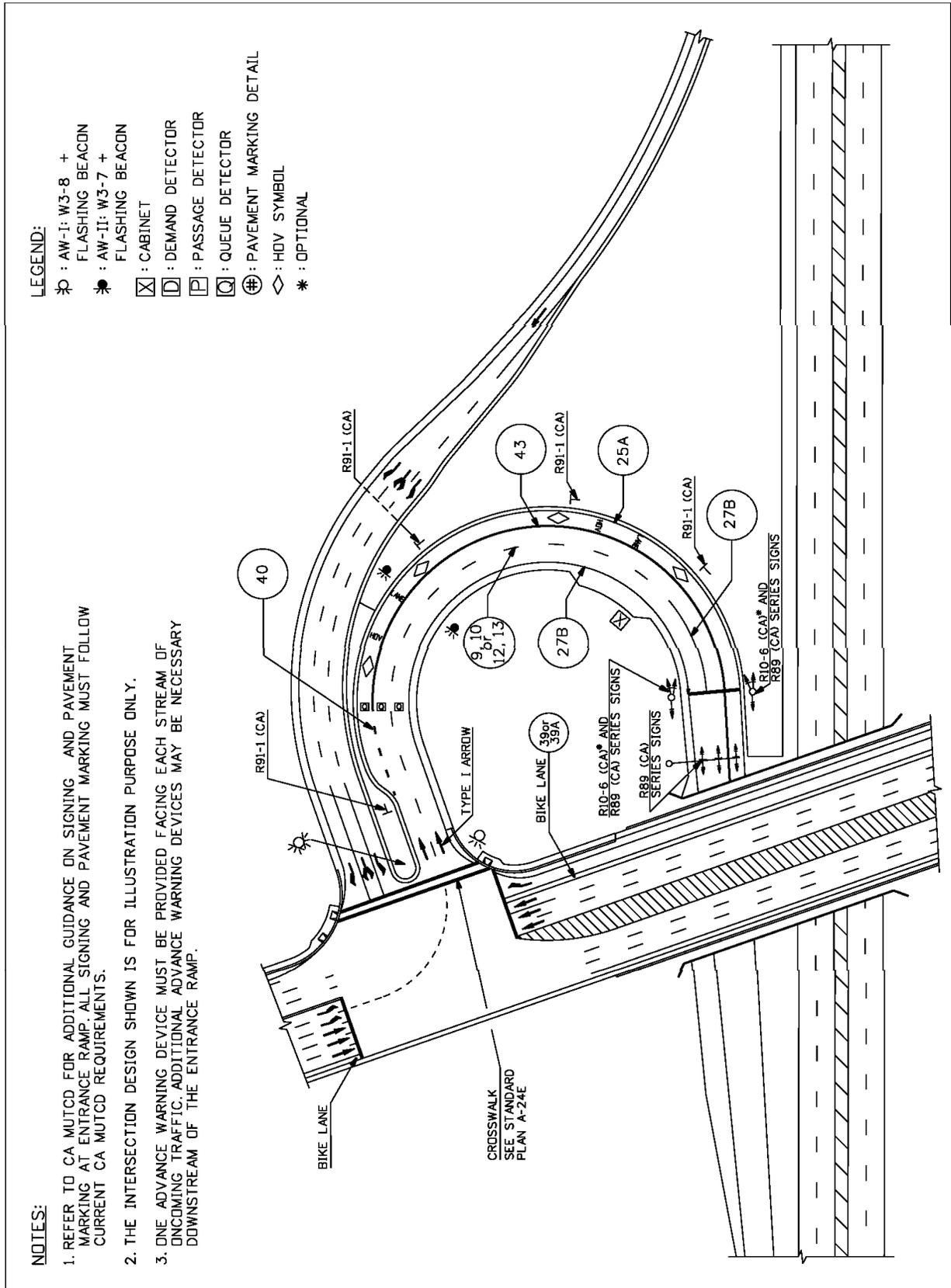




Figure 3-4

Typical Signing and Pavement Marking

(3-Lane Loop Entrance Ramp, 2 GP Lanes + 1 HOV Preferential Lane)

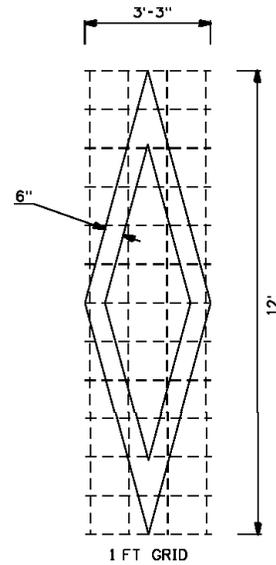
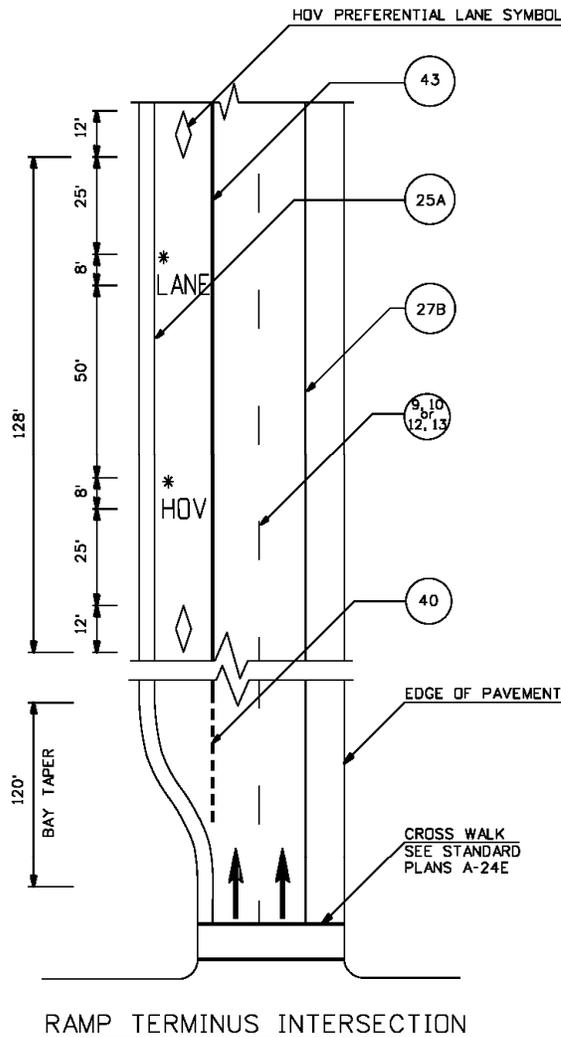




**Figure 3-6**  
**Typical HOV Preferential Lane Pavement Markings**

**NOTES:**

1. ONLY THE RAMP ENTRANCE AND THE BASIC 128 FT. LONG SEGMENT ARE SHOWN. THE 128 FT. LONG BASIC SEGMENT REPEATS FOR ACTUAL APPLICATION.
2. "HOV LANE" PAVEMENT MARKINGS ARE TO BE USED FOR INITIAL IMPLEMENTATION AND THEN ALLOWED TO WEAR OUT.



**HOV PREFERENTIAL LANE SYMBOL**  
 (SEE STANDARD PLANS A24-C)

**LEGEND:**  
 \* : OPTIONAL

Figure 3-7

Lane-Drop Transition Zone Pavement Markings

(2 GP Lanes + 1 HOV Preferential Lane on the Left Side)

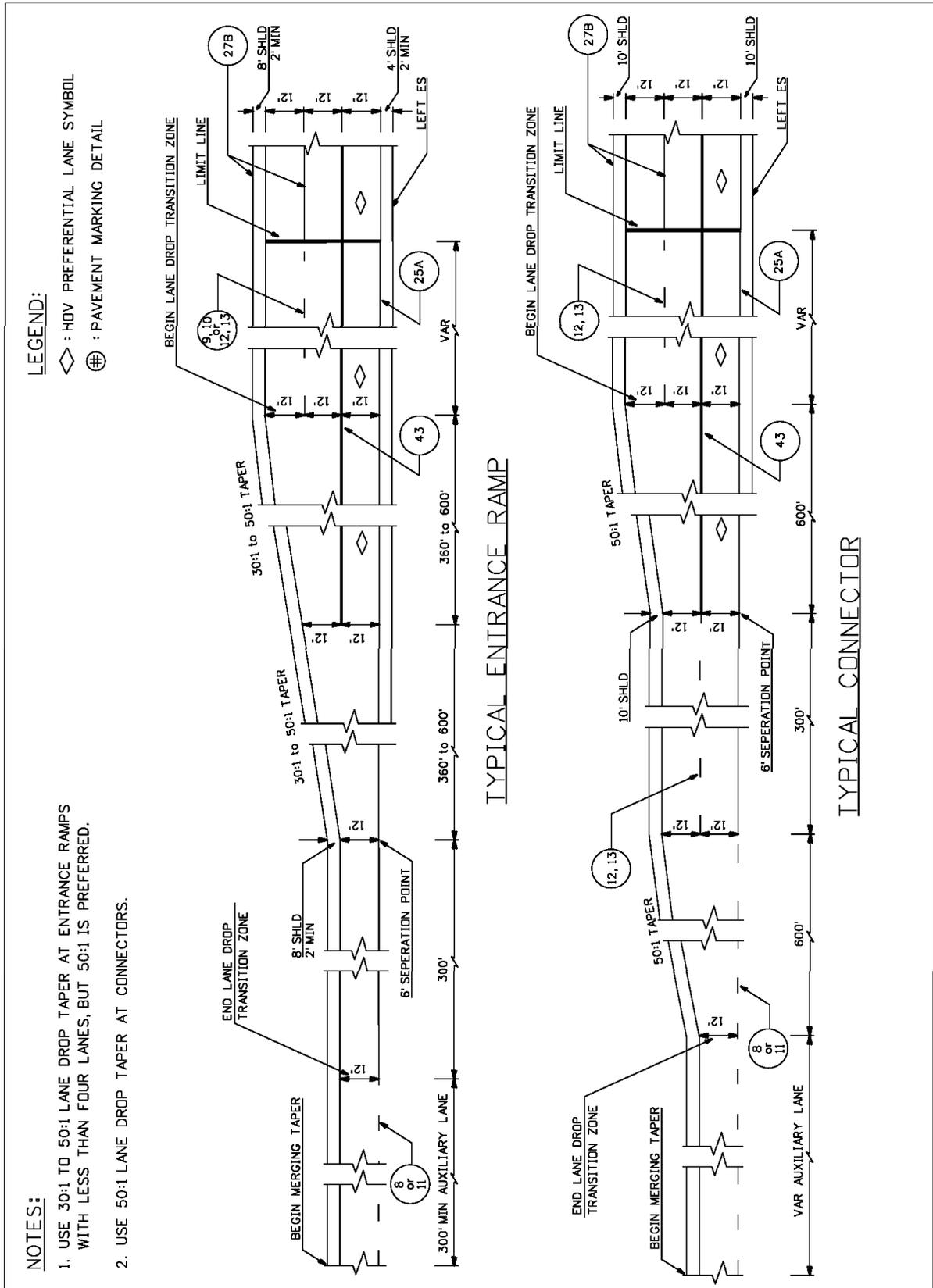
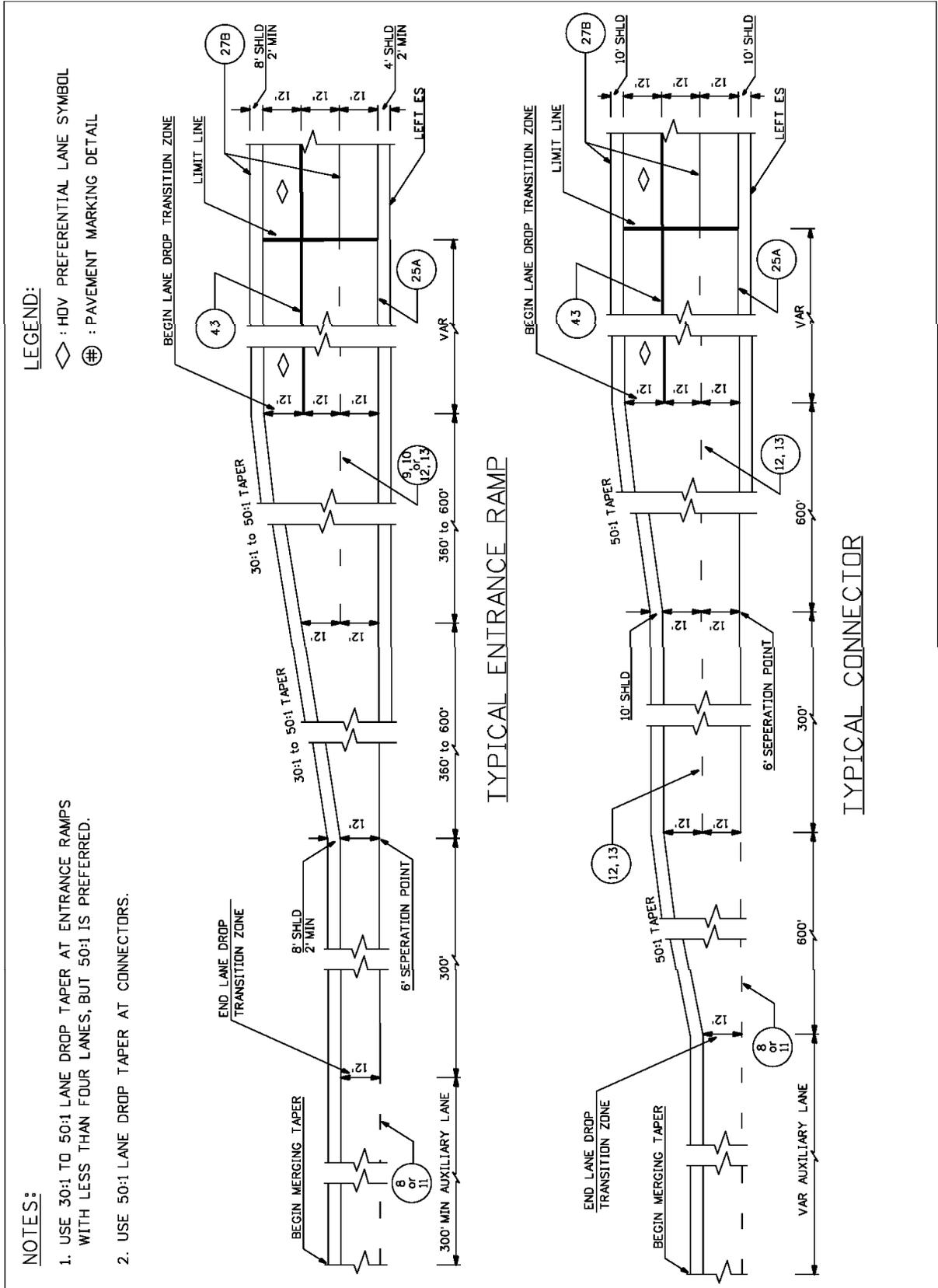


Figure 3-8

Lane-Drop Transition Zone Pavement Markings

(2 GP Lanes + 1 HOV Preferential Lane on the Right Side)



## ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ABO	Activated Blank-Out sign
AW	Advance Warning Device
CA MUTCD	California Manual on Uniform Traffic Control Devices
CALTRANS	California Department of Transportation
CHP	California Highway Patrol
CMS	Changeable Message Sign
CRZ	Clear Recovery Zone
ES	Edge of Shoulder
EMS	Extinguishable Message Sign
ETW	Edge of Traveled Way
FHWA	Federal Highway Administration
GP Lane(s)	General Purpose Lane(s)
HCM	Highway Capacity Manual
HDM	Highway Design Manual
HOV	High-Occupancy Vehicle
HOV PL	High-Occupancy Vehicle Preferential Lane
HQ	Headquarters
IP	Internet Protocol
ITS	Intelligent Transportation Systems
MPH	Miles per Hour (unit of speed)
MVP	Maintenance Vehicle Pullout
MUTCD	Manual on Uniform Traffic Control Devices
NDOT	Nevada Department of Transportation
NTCIP	National Transportation Communications for ITS Protocol
PARCLO	Partial Clover-leaf Interchange
PEER	Permit Engineering Evaluation Report
PR	Project Report
PSR	Project Study Report
PSSR	Project Scope Summary Report
PID	Project Initiation Document
PRT	Perception Response Time.
RM	Ramp Metering
RMIS	Ramp Metering Information System
RMDM	Ramp Metering Design Manual
SEC	Seconds (unit of time)
SOV	Single-Occupant Vehicle
TCP	Transmission Control Protocol
TMC	Transportation Management Center
TMS	Transportation Management System
VAC	Volts Alternating Current
VPH	Vehicles per Hour

## GLOSSARY

**ACCELERATION DISTANCE** (for Ramp Metering): The distance needed for entrance ramp vehicles to accelerate to freeway speeds from the ramp metering limit line. For a metered entrance ramp, this distance is measured from the entrance ramp limit line to the convergence point where the merging taper begins (2006 *HOV/Managed Lanes and Ramp Metering Design Manual*, NDOT).

**ACTIVATED BLANK-OUT SIGN**: A type of dynamic message sign that has the capability to show a blank message or one fixed message (*NTCIP 2103 Version V03*).

**ADVANCE WARNING SIGNS**: Signs posted on an entrance ramp (upstream of the limit line) or along an arterial that provides advance warning to motorists of the presence or operational status of ramp meters (2006 *HOV/Managed Lanes and Ramp Metering Design Manual*, NDOT).

**AUXILIARY LANE**: The portion of the roadway for weaving, truck climbing, speed change, or for other purposes supplementary to through-traffic movements (*HDM 62.1*). It is typically an additional lane on a freeway to connect an entrance ramp and an exit ramp (Chapter 9, *2010 HCM*).

**BACK OF QUEUE**: The maximum rearward extent of queued vehicles during metering period, as measured from the limit line to the last queued vehicle (Chapter 9, *2010 HCM*).

**BEACON**: A highway traffic signal with one or more signal sections that operates in a flashing mode (Chapter 1A, *2014 CA MUTCD*).

**CLEAR RECOVERY ZONE (CRZ)**: An unobstructed, relatively flat (4:1 or flatter), or gently sloping area beyond the edge of the traveled way, which affords the drivers of errant vehicles the opportunity to regain control (*HDM 309*).

**COLLECTOR-DISTRIBUTOR (C-D) ROAD**: A separated freeway system adjacent to a freeway, which connects two or more local road ramps or freeway connections to the freeway at a limited number of points (*HDM 62.3*).

**CONNECTOR**: A length of roadway between two freeways that allow the unimpeded flow of traffic.

**CONNECTOR METER**: A traffic control signal that regulates the entry of vehicles from one freeway to another freeway according to traffic conditions. The signal allows one or more vehicles per lane to enter on each green interval.

**CONVERGENCE POINT**: The point of convergence occurs where the right ETW of the entrance ramp is one lane width from the right ETW of the freeway.

**CORRIDOR**: A set of parallel transportation facilities, for example, a freeway and an arterial street (Chapter 9, *2010 HCM*).

**CYCLE**: A complete sequence of signal indications (Chapter 9, *2010 HCM*).

**CYCLE LENGTH**: The time elapsed between the endings of two sequential terminations of a given interval. For coordinated signals, this is measured by using the coordinated phase green interval (Chapter 9, *2010 HCM*).

**DELAY**: Additional travel time experienced by a driver, passenger, bicyclist, or pedestrian beyond that required to travel at the desired speed (Chapter 9, *2010 HCM*).

**DEMAND:** The number of vehicles or other roadway users desiring to use a given system element during a specific time period, typically 1 hour or 15 minutes (Chapter 9, *2010 HCM*).

**DEMAND DETECTOR:** The set of detectors on the upstream side of the limit line which detects vehicles demanding a green interval.

**DEMAND VOLUME:** The number of vehicles that arrive to use the facility. Under non-congested conditions, demand volume is equal to the observed volume (Chapter 9, *2010 HCM*).

**DESIGN SPEED:** A speed selected to establish specific minimum geometric design elements for a particular section of highway or bike path (*HDM 62.8*).

**DESIGN VOLUME:** A volume determined for use in design, representing traffic expected to use the highway facility. Unless otherwise stated, it is an hourly volume (*HDM 62.8*).

**DETECTORS:** Electronic devices that sense a vehicle's presence. Detectors can be pavement invasive or non-pavement invasive. See **INDUCTIVE LOOP DETECTORS**. Also see **PASSAGE DETECTOR** (*2006 HOV/Managed Lanes and Ramp Metering Design Manual*, NDOT).

**DIAMOND SYMBOL:** A diamond-shaped symbol placed on signs and/or pavement to designate an HOV preferential lane.

**DISTRICT:** For ease of management, Caltrans has divided California into 12 regions each labeled with a district number from one to twelve.

**DIVERGING:** A movement in which a single stream of traffic separates into two streams without the aid of traffic control devices (Chapter 9, *2010 HCM*).

**DOWNSTREAM:** The direction of traffic flow (Chapter 9, *2010 HCM*).

**ENFORCEMENT:** The function of maintaining the rules of the road and regulations to preserve the integrity of a facility. Enforcement is performed by enforcement agencies.

**ENFORCEMENT AREA:** An area used by enforcement personnel to monitor and enforce the compliance with ramp meter indications and entrance ramp HOV preferential lane occupancy requirements.

**ENGINEERING JUDGEMENT:** The evaluation of available pertinent information, and the application of appropriate principles, experience, education, discretion, provisions, and practices as contained in this RMDM and other sources, for the purpose of deciding upon the applicability, design, operation, or installation of a traffic control device. Engineering judgment shall be exercised by an engineer, or by an individual working under the supervision of an engineer, through the application of procedures and criteria established by the engineer. Documentation of engineering judgment is not required (Chapter 1A, *2014 CA MUTCD*).

**ENGINEERING STUDY:** The comprehensive analyses and evaluation of available pertinent information, and the application of appropriate principles, engineering judgment, experience, education, discretion, provisions, and practices as contained in this RMDM (and other sources) for the purpose of deciding upon the applicability, design, operation, or installation of a traffic control device or a highway facility. An Engineering study shall be performed by an engineer, or by an individual working under the supervision of an engineer, through the application of procedures and criteria established by the engineer. An Engineering study shall be documented (Chapter 1A, *2014 CA MUTCD*).

**ENTRANCE RAMP:** A ramp that accommodates merging maneuvers onto a freeway (*2006 HOV/Managed Lanes and Ramps Metering Design Manual*, NDOT).

**EXIT RAMP:** A ramp that accommodates diverging maneuvers by drivers exiting a freeway (2006 *HOV/Managed Lanes and Ramps Metering Design Manual*, NDOT).

**EXTINGUISHABLE MESSAGE SIGN (EMS):** Extinguishable Message Signs are static message signs that are illuminated when specific conditions occur on the State highway system. Their purpose is to inform the motorist of an advisory or request for action. The EMS can be configured as an internally illuminated message sign, a fixed sign with beacons or a Light Emitting Diode (LED) pixel message.

**FLASHING:** An operation in which a light source, such as a traffic signal indication, is turned on and off repetitively (Chapter 1A, 2014 *CA MUTCD*).

**FREEWAY:** A divided arterial highway with full control of access and with grade separations at intersections.

**FREEWAY WEAVING SEGMENT:** Freeway segments in which two or more traffic streams traveling in the same general direction cross paths along a significant length of freeway without the aid of traffic control devices (except for guide signs). (Chapter 9, 2010 *HCM*).

**GENERAL-PURPOSE (GP) LANES:** The travel lanes on a freeway or arterial street open to all traffic and vehicles (2006 *HOV/Managed Lanes and Ramps Metering Design Manual*, NDOT).

**GORE:** The term “exit gore” or “exit ramp gore” refers to an area immediately after the divergence of two roadways bounded by the edges of the through roadway and exit ramp. The term “entrance ramp gore” refers to a similar area immediately before the convergence of two roadways bound by the edges of the through roadway and entrance ramp (2006 *HOV/Managed Lanes and Ramps Metering Design Manual*, NDOT).

**HIGH-OCCUPANCY VEHICLE (HOV):** Motor vehicles with at least two or more persons, including carpools, vanpools, and buses. Only vehicles with the required occupancy levels are legally allowed to use HOV facilities. The required occupancy levels are usually expressed as either two or more (2+) or three or more (3+) passengers per vehicle (Chapter 1A, 2014 *CA MUTCD*).

**HIGH OCCUPANCY VEHICLE LANES:** An exclusive lane for vehicles carrying the posted number of minimum occupants or carpools, either part time or full time (*HDM* 62.8).

**INDUCTIVE LOOP DETECTOR:** A device used to detect the presence and passage of vehicles in a lane by sensing changes in an electromagnetic field surrounding the device when vehicles sit on or pass through it (Chapter 1, *Traffic Detector Handbook: Third Edition-Volume I, FHWA*).

**INTERCHANGE:** A system of interconnecting roadways in conjunction with one or more grade separations that provides for the movement of vehicles between two or more roadways on different levels (*HDM* 62.4).

**INTERSECTION:** The general area where two or more roadways join or cross, within which are included roadside facilities for traffic movements in that area (*HDM* 62.4).

**L-9 or TYPE L-9 INTERCHANGE:** See Figure 2-1. See **PARTIAL CLOVER-LEAF INTERCHANGE (PARCLO)**.

**LANE:** See **TRAFFIC LANE**.

**LANE-DROP TRANSITION ZONE:** Multi-lane entrance ramps typically taper down to a single lane width at the merge with the freeway mainline. The longitudinal length of traveled way accomplishing the lane-dropping process is called the lane-drop transition zone.

**LANE LINE:** The painted line that is used to mark a lane (Chapter 1A, *2014 CA MUTCD*).

**LIMIT LINE:** A solid white line not less than 12 nor more than 24 inches wide, extending across a roadway or any portion thereof to indicate the point at which traffic is required to stop in compliance with legal requirements (*Vehicle Code 377*).

**LOOP RAMP:** A ramp requiring vehicles to execute a left turn by turning right, accomplishing a 90-degree left turn by making a 270-degree right turn (Chapter 9, *2010 HCM*).

**MAINLINE:** The primary through roadway distinct from ramps, auxiliary lanes, and collector-distributor roads (Chapter 9, *2010 HCM*).

**MAINTENANCE VEHICLE PULLOUT (MVP):** A paved area or all-weather surface, adjacent to the entrance ramp shoulder where field personnel can park off the traveled way and safely access the work site (*HDM 62.1*).

**MARKING:** All pavement and curb markings, object markers, delineators, colored pavements, barricades, channelizing devices, and islands used to convey regulations, guidance, or warning to users (Chapter 3A, *2014 CA MUTCD*).

**MERGE:** A movement in which two separate streams of traffic traveling in the same general direction combine to form a single stream without the aid of traffic signals or other right-of-way controls (Chapter 9, *2010 HCM*).

**MERGING TAPER:** A taper to facilitate the convergence of separate streams of traffic into a single stream.

**MULTI-LANE:** A multi-lane traveled-way has more than one lane moving in the same direction. A multi-lane street, highway, or roadway has a basic cross-section comprised of two or more through lanes going in one or both directions. A multi-lane approach has two or more lanes moving toward the intersection, including turning lanes (Chapter 1A, *CA 2014 MUTCD*).

**NUMBER OF ENTRANCE RAMP LANES:** The number of lanes of an entrance ramp at the limit line.

**OCCUPANCY REQUIREMENT:** Any restriction that regulates the use of a facility or one or more lanes of a facility for any period of the day based on a specified number of persons in a vehicle (Chapter 1A, *2014 CA MUTCD*).

**PARTIAL CLOVER-LEAF INTERCHANGE (PARCLO):** An interchange with one to three (typically two) loop ramps and two to four diagonal ramps, with major turning movements desirably being made by right-turn exits and entrances (Chapter 9, *2010 HCM*). It is the type L-9 interchange according to the California Department of Transportation *Highway Design Manual*.

**PASSAGE DETECTOR:** Inductive loop detectors placed in each metered lane downstream of the limit line to detect passing vehicles. Passage detectors may count the number of vehicles that enter the freeway, and help determine the duration of the green interval of a metering signal (Chapter 10, *2006 Ramp Management and Control Handbook, FHWA*).

**PASSENGER-CAR EQUIVALENT:** The number of passenger cars that will result in the same operational conditions as a single heavy vehicle of a particular type under specified roadway, traffic, and control conditions (*2010 HCM*).

**PAVEMENT MARKING:** See MARKING.

**PEAK PERIOD:** The time period when the heaviest demand occurs on a given transportation facility or corridor. Usually the peak period is two or more hours in the morning and in the afternoon (2006 *HOV/Managed Lanes and Ramps Metering Design Manual*, NDOT).

**PLATOON:** A group of vehicles or pedestrians traveling together as a group, either voluntarily or involuntarily because of signal control, geometrics, or other factors (Chapter 9, 2010 *HCM*).

**PERCEPTION RESPONSE TIME:** The time needed by drivers for detection, recognition, decision, and reaction. (Section 2C.05, 2014 *CA MUTCD*).

**PROGRAMMABLE VISIBILITY (PV) SIGNAL HEAD OR PV HEAD:** Signal heads using special optical mechanisms to limit the visibility, so the indications can only be viewed from certain intended directions.

**QUEUE:** A line of vehicles, bicycles, or persons waiting to be served due to traffic control, a bottleneck, or other causes (Chapter 9, 2010 *HCM*).

**QUEUE OVERRIDE:** A process that adjusts the metering rate based on the traffic conditions at the queue detectors to shorten the length of the queue.

**RAMP:** A dedicated roadway providing a connection between two other roadways; at least one is typically a high-speed facility such as a freeway, multi-lane highway, or collector-distributor roadway (Chapter 9, 2010 *HCM*).

**RAMP-FREEWAY JUNCTION:** The point of connection between a ramp and a high-speed facility such as a freeway, multi-lane highway, or collector-distributor roadway (Chapter 9, 2010 *HCM*).

**RAMP METER:** A traffic signal that controls the rate of entry of vehicles from a ramp onto a limited access facility; the signal allows one or two vehicles to enter on each green or green flash (Chapter 9, 2010 *HCM*).

**RAMP METERING:** A vehicular traffic management strategy which utilizes a system of traffic signals on freeway entrance and connector ramps to regulate the volume of vehicles entering a freeway corridor in order to maximize the efficiency of the freeway and thereby minimizing the total delay in the transportation corridor (*HDM* 62.8).

**RAMP TERMINAL:** A junction of a ramp with a surface street serving vehicles entering or exiting a freeway. See **INTERCHANGE RAMP TERMINAL** (Chapter 9, 2010 *HCM*).

**REGULATORY SIGNS:** Signs used to inform highway users of traffic laws or regulations, and indicate the applicability of legal requirements.

**ROADBED:** That portion of the roadway extending from curb line to curb line, or shoulder line to shoulder line. Divided highways are considered to have two roadbeds (*HDM* 62.1).

**ROADWAY:** That portion of the highway included between the outside lines of the sidewalks, or curbs and gutters, or side ditches-including also the appertaining structures and all slopes, ditches, channels, waterways, and other features necessary for proper drainage and protection (*HDM* 62.1).

**SEPARATION POINT:** The 6-foot separation point is where the right edge of traveled way (ETW) of the freeway and the left ETW of the merging lane(s) are 6 feet apart; and the 23-foot separation point is where they are 23 feet apart.

**SHOULDER:** The portion of the roadway contiguous with the traveled way for accommodations of stopped vehicles, for emergency use, and for lateral support of base and surface courses (*HDM* 60.2).

**SIGHT DISTANCE:** The distance a person can see along an unobstructed line of sight (*2006 HOV/Managed Lanes and Ramps Metering Design Manual*, NDOT).

**SIGN:** A device mounted on a fixed or portable support whereby a specific message is conveyed by means of words or symbols, officially erected for the purpose of regulating, warning, or guiding traffic.

**SIGNAL BACKPLATE:** A thin strip of material that extends outward from the signal head, providing a background for improved signal lens visibility (*Chapter 4A, 2014 CA MUTCD*).

**SIGNAL HEAD:** An assembly of one or more signal sections (*Chapter 4A, 2014 CA MUTCD*).

**SIGNAL HOUSING:** That part of a signal section that protects the light source and other required components (*Chapter 4A, 2014 CA MUTCD*).

**SIGNAL LENS:** That part of the signal section that redirects the light coming directly from the light source and its reflector, if any (*Chapter 1A, 2014 CA MUTCD*).

**SIGNAL LOUVER:** Device mounted inside a signal visor to restrict visibility of a signal indication from the side or to limit the visibility of the signal indication to a certain lane or lanes, or to a certain distance from the limit line (*Chapter 1A, 2014 CA MUTCD*).

**SIGNAL SECTION:** The assembly of signal housing, signal lens, light source and other electronic components into one signal indicator (*Chapter 4A, 2014 CA MUTCD*).

**SIGNAL VISOR:** Part of a signal section that directs the signal indication specifically to traffic approaching the signal and reduces the effect of direct external light entering the signal lens (*Chapter 1A, 2014 CA MUTCD*).

**SINGLE OCCUPANT VEHICLE (SOV):** A motor vehicle carrying only one person.

**SPACING:** The distance between two successive vehicles in a traffic lane, measured from the same common feature of the vehicles (e.g. rear axle, front axle, or front bumper). (*Chapter 9, 2010 HCM*).

**SPEED CHANGE LANE:** An auxiliary lane, including tapered areas, primarily used for the acceleration or deceleration of vehicles entering or leaving the through traffic lanes (*HDM 62.1*).

**SPEED LIMIT:** The maximum (or minimum) speed applicable to a section of highway as established by law or regulation (*Chapter 1A, 2014 CA MUTCD*).

**STOPPING SIGHT DISTANCE:** The minimum stopping sight distance is the distance required by the user, traveling at a given speed, to bring the vehicle or bicycle to a stop after an object a minimum of 0.5-foot high on the road becomes visible.

**STORAGE:** The number of vehicles in queue.

**STORAGE LENGTH:** The length of roadway, such as an entrance ramp available for storing queued vehicles.

**TAPER:** A ratio at which traffic lane width longitudinally reduces or increases.

**TRAFFIC CONTROL DEVICE:** A sign, signal, marking, or other device used to regulate, warn, or guide traffic (*Chapter 9, 2010 HCM*).

**TRAFFIC LANE:** The portion of the traveled way for the movement of a single line of vehicles (*HDM 62.1*).

**TRANSPORTATION MANAGEMENT CENTER (TMC):** A central physical location from which transportation management activities, field elements, central applications, and the staff that supports them are managed. TMCs are operated in partnership with the California Highway Patrol and other transportation and emergency response organizations (*DD 70*).

**TRAFFIC SIGNAL:** A power operated traffic control device except signs, barricade warning lights, and steady burning electric lamps, by which traffic is regulated, warned, or alternately directed to take specific actions (*HDM 62.8*).

**TRAFFIC VOLUME:** See **VOLUME**.

**TRAVELED WAY:** The portion of the roadway for the movement of vehicles and bicycles, excluding of shoulders (*HDM 62.1*).

**TRUCK:** A heavy vehicle engaged primarily in the transport of goods and materials or in the delivery of services other than public transportation (Chapter 9, *2010 HCM*).

**TURNING MOVEMENT:** Traffic that makes a designated turn at an intersection.

**TYPE 1 STANDARD:** A tubular steel post mounted onto a concrete base, used to provide support for ramp metering signal heads. The post is typically circular in shape and 10 feet in length.

**TYPE 170 CONTROLLER:** A microprocessor-based device used to control ramp meter signals based on information from the detectors (Chapter 2, *Traffic Detector Handbook: Third Edition-Volume I, FHWA*).

**TYPE 2070 CONTROLLER:** A VME (Versa-Module Europe) based controller utilizing a 16 bit microprocessor that can be used to control ramp meter signals based on information from the detectors. It has the capability of providing more functionality than the Type 170 controller (Chapter 2, *Traffic Detector Handbook: Third Edition-Volume I, FHWA*).

**TYPE L-9 INTERCHANGE:** See **L-9 INTERCHANGE**, and **PARTIAL CLOVER-LEAF INTERCHANGE (PARCLO)**.

**UPSTREAM:** The direction from which traffic is flowing (Chapter 9, *2010 HCM*).

**VEHICLE:** Any motorcycle, car, truck, van, bus, or rail car designed to carry passengers or goods.

**VEHICLE OCCUPANCY:** The number of people in a car, truck, bus, or other vehicle.

**VOLUME:** The number of vehicles passing a given point during a specified period of time (*HDM 62.8*).

**WARNING SIGN:** A sign that gives notice to road users of a situation that might not be readily apparent (Chapter 1A, *2014 CA MUTCD*).

**WEAVING:** The crossing of two or more traffic streams traveling in the same direction along a significant length of highway without the aid of traffic control devices (except for guide signs). (*2010 HCM*).

**WEAVING SECTION:** One-way highway segments where the pattern of traffic entering and leaving at contiguous points of access resulting in vehicle paths crossing each other. Weaving sections may occur within an interchange, between an entrance ramp and exit ramp of successive interchanges, and on segments of overlapping roadways.

**WEAVING SEGMENT:** See **FREEWAY WEAVING SEGMENT**.

## REFERENCES

American Association of State Highway and Transportation Official (AASHTO), policy on Geometric Design of Highways and Streets, 6<sup>th</sup> Edition, 2011.

American Association of State Highway and Transportation Official (AASHTO), Guide for High Occupancy Vehicle Facilities, November 2004.

Arizona Department of Transportation (ADOT), Ramp Meter Design Operations and Maintenance Guidelines, August 2003.

California Department of Transportation (Caltrans), Highway Design Manual, 6<sup>th</sup> edition, 2012. Sacramento, California.

California Department of Transportation (Caltrans), California Manual on Uniform Traffic Control Devices, 2014, Sacramento, California.

California Department of Transportation (Caltrans), Signal, Lighting, and Electrical Systems Design Guide, 5<sup>th</sup> Edition, April 2007, Sacramento, California.

California Department of Transportation (Caltrans), Ramp Meter Design Manual, 2000, Sacramento, California.

California Department of Transportation (Caltrans), STANDARD PLANS 2010. Sacramento, California.

California Department of Transportation (Caltrans), STANDARD SPECIFICATIONS 2010. Sacramento, California.

Federal Highway Administration (FHWA), Ramp Management and Control Handbook, FHWA- HOP-06-001 January 2006.

Federal Highway Administration (FHWA), Traffic Detector Handbook, Third Edition. Publication No. FHWA-HRT-06-108, Federal Highway Administration, Turner-Fairbank Highway Research Center, McLean, VA 22101, October, 2006.

Nevada Department of Transportation (NDOT), HOV/Managed Lanes and Ramps Metering Design Manual, March 2006.

Texas Transportation Institute (TTI), Design and Operations Criteria for Ramp Metering, Project Summary Report 2121-5, January 2001.

Washington State Department of Transportation (WSDOT), Design Manual, June 2009.

## APPENDIX A: Deputy Directive 35-R1

# Deputy Directive

Number: DD-35-R1

**Refer to**

*Director's Policy:* 08-Freeway System Management

*Effective Date:* January 06, 2011

*Supersedes:* DD-35 (1-3-95)

*TITLE* Ramp Metering

---

*POLICY*

The California Department of Transportation (Department) is committed to using ramp metering as an effective traffic management strategy to maintain an efficient freeway system, and protect the investment made in constructing freeways by keeping them operating at or near capacity.

Each district that currently operates, or expects to operate, ramp meters within the next ten years, shall prepare a Ramp Metering Development Plan (RMDP). RMDP shall contain a list of each ramp meter location that is currently in operation or planned for operation within the next ten years. Each district shall update its RMDP biennially and ensure that future ramp meter locations are included in the local Congestion Management Plans.

Provisions for ramp metering shall be included in any project that proposes additional capacity, modification of an existing interchange, or construction of a new interchange, within the freeway corridors identified in the RMDP, regardless of funding source. These provisions, at each onramp, may include procurement of additional right of way, changes to ramp geometry to accommodate queue storage, installation of High Occupancy Vehicle (HOV) preferential lanes, deployment of electrical and communication systems, and construction of California Highway Patrol (CHP) enforcement areas and maintenance vehicle pullouts.

The guidelines, policies and procedures, and standards contained in the Ramp Metering Design Manual (RMDM), together with the design criteria in the Highway Design Manual (HDM), shall be applied when planning and designing ramp meters.

HOV preferential lanes shall be provided wherever ramp meters are installed, and each HOV preferential lane should be metered. Each district shall provide justification for deviation from the HOV preferential lane installation policy and obtain concurrence from the Headquarters Traffic Operations District Liaison.

## DEFINITION/BACKGROUND

Ramp metering is a traffic management strategy that utilizes a system of traffic signals at freeway entrance, and connector ramps to regulate the volume of traffic entering a freeway corridor in order to maximize the efficiency of the freeway, and thereby minimize the total delay in the transportation corridor.

Ramp metering has been an effective tool in reducing congestion and overall travel time on California freeways and local streets since the late 1960s. The added benefits include the reduction of both congestion- related collisions and air pollution.

The Department has installed over 2,200 ramp meters throughout the State. Installation of ramp meters on all urban freeway entrance ramps, including freeway-to-freeway connectors will be considered as a Departmental best practice, where ramp metering will maintain or improve effective operations along freeway corridors.

RMDM is a comprehensive document containing ramp meter design standards, design procedural requirements, and operational policies adopted statewide. RMDM is used to guide the Department's designers, as well as consulting engineers, and city/county engineers performing design work on freeways.

## RESPONSIBILITIES

### Chief, Division of Traffic Operations:

- Develops, implements, and maintains statewide policies, manuals, and guidelines for ramp metering.
- Provides direction and assistance to district staff on ramp metering activities, as well as resources for training district staff.
- Ensures and supports the inclusion of ramp meters in projects within freeway segments containing any of the locations listed in RMDP.
- Ensures consistency among different districts on the development and implementation of ramp metering projects.
- Provides direction, training and assistance to district Traffic Operations staff on the development of the RMDP in partnership with the Division of Transportation Planning.
- Leads the development of statewide RMDP.
- Maintains a statewide inventory of planned, programmed and constructed ramp meters.

### Chief, Division of Transportation Planning:

- Work collaboratively with Chief, Division of Traffic Operations in the development of statewide RMDP.
- Ensures consistency among different districts on the development of their respective RMDP.
- Provides direction, training and assistance to district Planning staff on the development of the RMDP in partnership with the Division of Traffic Operations.
- Work collaboratively with the Division of Traffic Operations in the development, implementation, and maintenance of statewide policies, manuals, and guidelines for ramp metering.

Chiefs, Divisions of Design and Construction:

- Ensure that Division policies and manuals support the current ramp metering policies. These policies include making provisions for ramp meters in project development, accommodating HOV at onramps, and construction of CHP enforcement areas and maintenance vehicle pullouts at ramp meters.
- Ensure that staff and practices support ramp metering policies.

Chief, Divisions of Maintenance:

- Leads the development of acceptance procedures to hand-off ramp meter systems to the Division of Maintenance.

District Directors:

- Ensure the provision of resources for the entire life cycle of ramp metering activities. These activities include ramp metering planning, design, construction, operations, and maintenance.
- Establish local agency support for ramp metering.
- Assign lead responsibility for development, maintenance, and implementation of RMDP in the District.

Deputy District Directors, Planning:

- In coordination with District Traffic Operations, develop and maintain the district RMDP, program funding and implement ramp metering projects with the affected local and regional transportation stakeholders.
- Submit all future ramp metering locations contained in the RMDP for inclusion in local Congestion Management Plans, Regional Transportation Plans, Department System Planning documents and other applicable planning documents developed by other agencies or the Department.
- Ensure consistency of ramp metering plans with neighboring Districts' ramp metering plans.
- Provide traffic forecasting for development of RMDP in coordination with Traffic Operations.

Deputy District Directors, Construction, Design, and Project Management:

- Ensure that provisions for ramp metering are included in all projects involving interchange modification and freeway improvements at locations identified in RMDP.
- Ensure that each existing ramp meter affected by construction projects remains operational throughout the construction period.

Deputy District Directors, Operations:

- In coordination with District Planning, develop and maintain the district RMDP.
- Develop an inventory of planned, programmed and constructed ramp meters.
- Assist Deputy District Directors, Planning to coordinate with local and regional transportation stakeholders, on the implementation of ramp metering projects and document the efforts made toward coordination and record any concurrence obtained.
- Provide district personnel with technical assistance and support on the design and operation of ramp metering systems.
- Coordinate with CHP regarding enforcement issues at ramp meters.
- Implement ramp metering policies and procedures.
- Provide justification for deviation from established ramp metering policies. Ensure consistency of ramp metering practices with neighboring Districts.

Deputy District Directors, Maintenance:

- Ensure that each ramp meter is operational.
- Ensure regular inspection of each ramp meter.
- Ensure the minimization of traffic delay when repairing existing ramp meters.

District Project Managers:

- Ensure that ramp meters are included in the earliest stage of project development and are not eliminated during the project delivery process.
- Identify necessary project resources for the installation of ramp meters.
- Work closely with district Traffic Operations to ensure that ramp metering requirements are satisfied.
- Ensure the approval of Fact Sheet for exception to ramp metering policies.

District Ramp Metering Staff:

- Support the development and maintenance of the district RMDP.
- Review ramp metering plans and specifications, and coordinate with Design, Construction and Maintenance to design, construct, operate, and maintain ramp meters.
- Work with district Construction to ensure that each existing ramp meter affected by construction projects remains operational throughout the construction period.
- Prepare, review, and implement ramp metering rates that will maintain effective operations along freeway corridors.

District Design Engineers and Office Engineers:

- In coordination with district Traffic Operations, identify and incorporate the need for ramp meters and HOV preferential lanes in the Project Study Report, Project Report, and Environmental Documents.
- Provide Standard Special Provisions and Contract Plans for ramp metering elements, including system integration needs such as communications, and compatibility of software.
- Provide Fact Sheet for exception to ramp metering policies.

District Construction Engineers (Electrical and Civil), Resident Engineers, and Encroachment Permit Inspectors:

- Ensure that ramp metering elements are installed according to the Standard Special Provisions, Standard Specifications, and Contract Plans.
- Ensure that each ramp meter affected by construction projects remains operational throughout the construction period unless otherwise specified in the contract documents.
- Immediately notify district Traffic Operations personnel of any change in status of each ramp meter affected by construction projects.
- Ensure that each ramp meter affected is fully reviewed, tested, and operational prior to accepting a contract and closing the project ID number.

**APPLICABILITY**

All Department employees involved with ramp metering activities.

  
MALCOLM DOUGHERTY  
Chief Deputy Director, Interim

  
Date Signed

# APPENDIX B: SAMPLE – EXCEPTION(S) TO RAMP METERING POLICY FACT SHEET

Dist - Co - Rte - PM  
 Program Code  
 Project Number  
 Project Name

## FACT SHEET EXCEPTION TO RAMP METERING POLICY



Prepared by:

DATE

\_\_\_\_\_

( NAME )

\_\_\_\_\_

Approval recommended by:

\_\_\_\_\_

*DISTRICT RAMP METERING BRANCH CHIEF*

DATE

\_\_\_\_\_

Concurrence by:

\_\_\_\_\_

*HQ TRAFFIC OPERATIONS DISTRICT LIAISON*

DATE

\_\_\_\_\_

Approval By:

\_\_\_\_\_

*DISTRICT DEPUTY DIRECTOR, TRAFFIC OPERATIONS*

DATE

\_\_\_\_\_

### 1. PROJECT DESCRIPTION

Briefly describe the project. Note the type of project and/or major elements of work to be done.

### 2. RAMP METERING POLICY NON-COMPLIANCE FEATURES

Describe the proposed or existing ramp metering policy non-compliance feature(s). (Note: Deviations from advisory or mandatory design standards shall be addressed as required by the *Project Development Procedures Manual*, the *Highway Design Manual* and applicable District Directives.)

### 3. REASON FOR THE EXCEPTION

Be thorough but brief. Supportive factors may include right-of-way or space constraints, environmental concerns, inordinate costs, etc. Show an estimate of the added cost above the proposed project cost that would be required to conform to the ramp metering policy for which exception is being documented. The estimate does not have to be highly developed but must be realistic.

**4. FUTURE CONSTRUCTION**

**Describe any planned future projects in the immediate vicinity of the requested ramp meter exception, but do not make any commitments (e.g., ramp metering as part of future projects) unless there is a certainty that they can be followed through.**

**5. REMARKS**

Note clarifying remarks. Discuss impacts on project delivery schedule and project costs, if any. Discuss impacts of ramp metering policy non-compliance features.

**6. ATTACHMENTS**

Provide a locations map and/or vicinity map for the project, indicating the location of the requested exception(s) to the ramp metering policy. Also provide cross-sections and/or special details as necessary to illustrate the policy non-compliance condition. Letters, resolutions, traffic studies, etc., which help to clarify the reasons for the exception request, may be attached.

## APPENDIX C: RAMP METERING DESIGN CHECKLIST

### GEOMETRIC DESIGN

1. Number of lanes:
  - Provide one metered lane per 900 vehicles per hour (vph) demand. Calculate General Purpose (GP) and High Occupancy Vehicle (HOV) demand separately.
  - Use 1GP + 1HOV lane, when GP demand <900 vph, HOV demand <900 vph.
  - Use 2GP + 1HOV lane, when GP demand is 900~1800 vph, HOV demand <900 vph.
  - Use 3GP + 1HOV lane, when GP demand >1800 vph, HOV demand <900 vph.
  - Shall install an HOV Preferential Lane (HOV PL) at all metered entrance ramps/connectors per DD-35-R1. If deviate, prepare an HOV PL policy exception fact sheet.
2. Lane and Shoulder Width:
  - Use 12 foot lanes, if adding truck exit tracking, see HDM 504.3.
  - Follow HDM Table 302.1 for shoulder width.
3. Pavement Structural Section:
  - Use full structural section for shoulder.
  - Consider concrete pad next to the limit line for loop longevity.
4. Queue Storage:
  - Use 7% of peak hour design volume (consider GP and HOV demand separately) as 'single' lane storage.
  - Use 29 feet per vehicle to determine storage length.
5. Acceleration Distance:
  - Use 5 mph as allowable merging speed differential per the Green Book.
  - Consider trucks or buses when selecting an acceleration rate. In 1988, passenger car acceleration rate was measured as 5.47 ft/s<sup>2</sup> in District 4.
6. Taper Design:
  - Use 50:1 min. as merging (ramp onto freeway) taper.
  - Use 30:1 to 50:1 lane-drop taper. For connectors, use 50:1 minimum.
7. Auxiliary Lane:
  - Install 300 feet minimum for every metered entrance ramp.
  - Install 1000 feet minimum, when truck percentage and ascending grades warrant.
  - Install 1000 feet minimum, when design volume >1500 vph.
8. CHP Enforcement Area:
  - Shall be provided downstream of the limit line.
9. Maintenance Vehicle Pullout (MVP):
  - Shall be provided upstream of the limit line.
  - Consider all-weather walking path between MVP and controller cabinet.
10. Ramp Terminal Intersection Design:
  - Eliminate free-flow access design.
  - Consider pedestrian/bicycle traffic, bulb-out the HOV lane access at the ramp entrance.

### ELECTRICAL DESIGN

11. Placement of Signal Heads:
  - Install at least one head per controlled lane as required by the CA MUTCD.
  - Ensure signal visibility at the controller cabinet.
  - Install CHP enforcement heads which should be visible at the CHP enforcement pads.
  - Keep 6 feet minimum between bottom of signal housing and center of adjacent lane.
  - Align overhead signal heads with center of the controlled lanes.
  - Install Type 1 standards only at loop ramps outside of the mainline clear recovery zone.
12. Placement of Cabinets, Conduits, and Signal Standards:
  - Place cabinets outside the required Clear Recovery Zone (CRZ).
  - Place Type 1 standards 3 feet off ETW at the limit line (but must be outside of mainline CRZ).
  - Remove or re-design signal standards at gore area for worker safety.

- Consider trade-offs between overhead and roadside signal supports.
  - Obtain structural approval when non-standard supporting structures are used.
13. Placement of Detectors:
- Check the types, location, and sizes (e.g. mainline demand, entrance ramp demand, passage, count, and queue loops designed).
  - Equip an HOV preferential lane the same way as any other metered entrance ramp lanes.
  - Equip metered connectors the same way as metered entrance ramps.
  - Install count loops at exit ramps.
14. Check Other Electrical Design Details:
- Select cabinet type, location, and demarcation.
  - Select conduit type, location, and size.
  - Select and design communication system for ramp meters (fiber, wireless, or lease?).
  - Include provisions and costs for communications equipment.
  - Consider integration needs with central system in specifications and estimates.

### **SIGNING AND PAVEMENT MARKING DESIGN**

15. Placement of Limit Line (Stop Bar):
- Trade-offs between the necessary acceleration length and storage length.
  - Consult with District Ramp Metering Branch.
16. Regular Signing and Pavement Marking:
- Check the type, location, and dimension of signing and pavement marking.
  - Install solid lane line between HOV and GP lanes.
  - Install HOV PL sign R91-1 (CA) package based on part-time or full-time operations.
  - Do not use staggered limit lines.
  - Install R89-2 (CA) on the mast arms and R89 (CA) or R89-1 (CA) at the limit line.
17. Placement of advance warning signs:
- Install advance warning signs at the entrance facing oncoming traffic.
  - Use two advance warning signs on each side of multi-lane entrance ramps.
  - Install additional advance warning signs based on geometry and back of queue location.
  - Obtain structural approval when non-standard supporting structures are used.

## APPENDIX D: INSTRUCTIONS FOR USING ARRIVAL DISCHARGE CHART

The chart (see sample on page #62-63) is designed for arrival and discharge rates in vehicles per hour (vph), in 0.1-hour (6 minutes) time intervals. The area of each grid under the curve represents  $100 \text{ vph} \times 0.1 \text{ hour} = 10$  vehicles. The horizontal axis represents the time intervals with a scale of 0.1 hour per unit. The vertical axis on the left represents arrival or discharge rates in vph; while the vertical axis on the right represents the area, in vehicles, of the grids formed by the corresponding arrival or discharge rate and 0.1-hour time interval, divided by 10. Instructions on how to use the chart are provided below.

1. Plot the arrival rates for each 0.1-hour (6 minutes) time period in bar graph style. The chart can accommodate a maximum study period of 1.6 hours.
2. On the same chart, plot the discharge rate in the same manner.
3. Identify the point where the arrival rate just starts to exceed the discharge rate as the starting point, and set this point as time zero. Ignore the portion prior to the starting point where the arrival rate fails to exceed the discharge rate. This portion experiences no delay.
4. For each time interval of the chart to the right of the starting point where delay or queue begins, calculate the area under the arrival rate curve. Record on Line A the number shown on the right vertical axis of the graph that corresponds to the arrival rate.
5. Do the same for the area under the discharge rate curve and record on Line B.
6. Calculate the delta ( $\Delta_i$ ) for each time interval,  $i$ . This is the cumulative difference of the area on Lines A and B, taken from time zero to the time interval in question.
7.  $\Delta$  continues to increase as long as the arrival rate exceeds the discharge rate. At the point where the discharge rate exceeds the arrival rate,  $\Delta$  begins to decrease representing dissipation of the queue, until  $\Delta$  reaches zero when the queue totally vanishes.
8. Determine the maximum  $\Delta$  and the sum of all the  $\Delta_i$ . Enter the data on the left side of the chart to determine the maximum queue (vehicles), total delay (vehicle-hour), total vehicles delayed, and average delay.

The number of vehicles in the queue at the end of any 0.1-hour time period is equal to the total number of arrivals minus the total number discharged up to the end of that time period. This is calculated by taking the difference between the areas under the arrival and discharge curves, and multiplying by 10. The maximum queue occurs at the end of the 0.1-hour time period which marks the greatest difference between arrival and discharge areas.

Any  $\Delta_i \times 10$  represents the number of vehicles stored in the queue for that time period. The delay in each 0.1-hour time period equals the number of vehicles in the queue ( $\Delta \times 10$ ) multiplied by the length of time (0.1-hour). For example, if  $\Delta_i$  for one of the columns is 3.2, the delay for that 0.1-hour is  $3.2 \times 10 \times 1/10 = 3.2$  vehicle-hours. The total delay is summation of the individual 0.1-hour time increments, so the total delay =  $\sum_{i=1}^n \Delta_i$ ,  $n$  is the total number of intervals.

The total number of vehicles delayed is the same as the total number of arriving vehicles that arrives during the time when there is a queue. The total number of vehicles delayed =  $\sum \Delta_i \times 10$ .

**ARRIVAL DISCHARGE CHART**

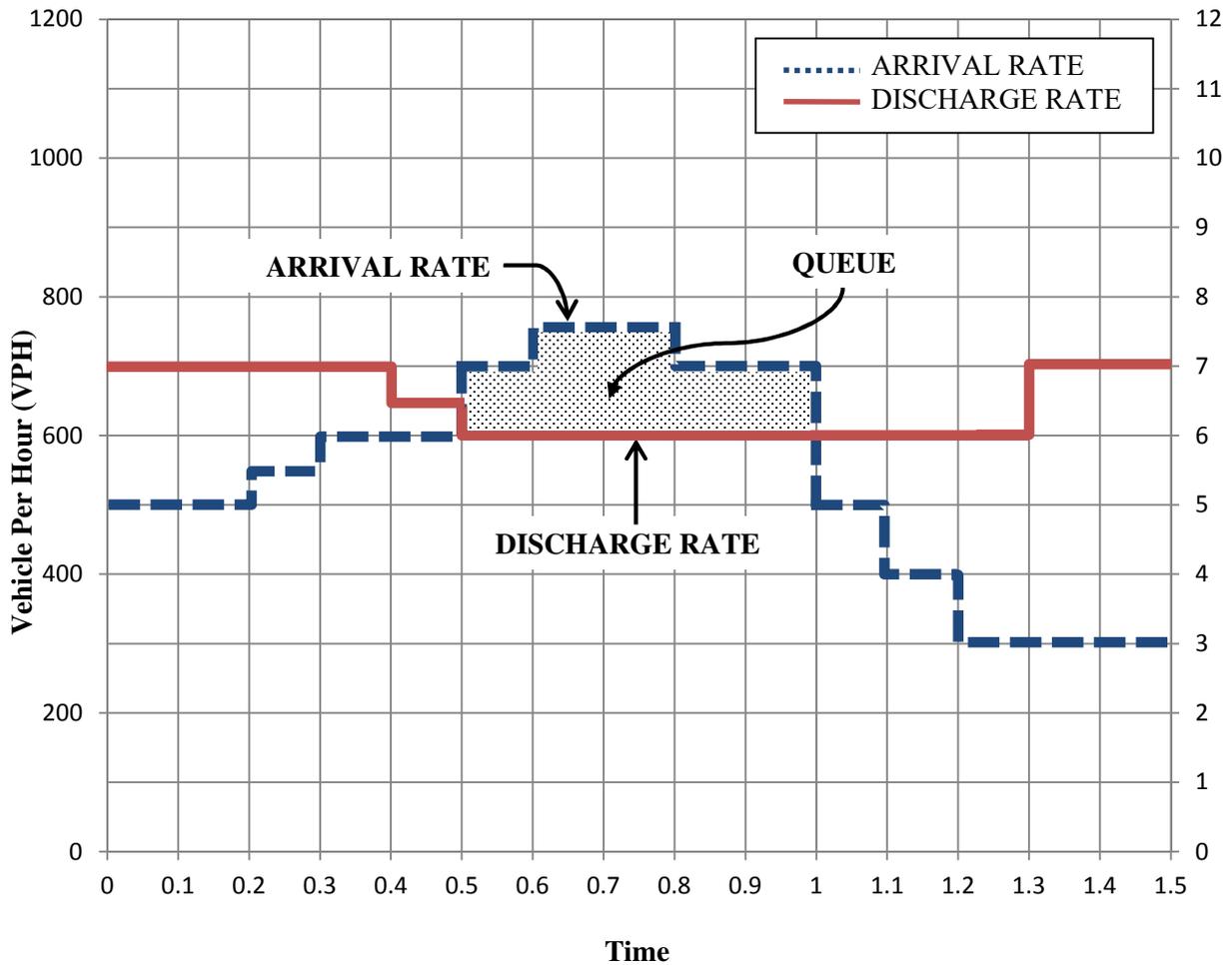
ROUTE     10     INTERCHANGE     BROWN ROAD      
 RAMP     NB-EB    

BEGINNING TIME     0630     RAMP COUNT DATE     05/10/92    

MAX QUEUE = MAX  $\Delta$  x 10 =     6.04     x 10 = 60.4  $\approx$  60 VEHICLES

TOTAL DELAY =  $\Sigma\Delta$  =     26.76     VEHICLES HOURS

TOTAL VEHICLES DELAYED =  $\Sigma A$  x 10 =     480     VEHICLES



A. Arrival	—	—	—	—	7.00	7.52	7.52	7.00	7.00	5.00	4.00	3.00	—	—
B. Discharge					6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00		
$\Delta = \Sigma A - \Sigma B$					1.00	2.52	4.04	5.04	<b>6.04</b>	5.04	3.04	0.04		

MAX  $\Delta$

