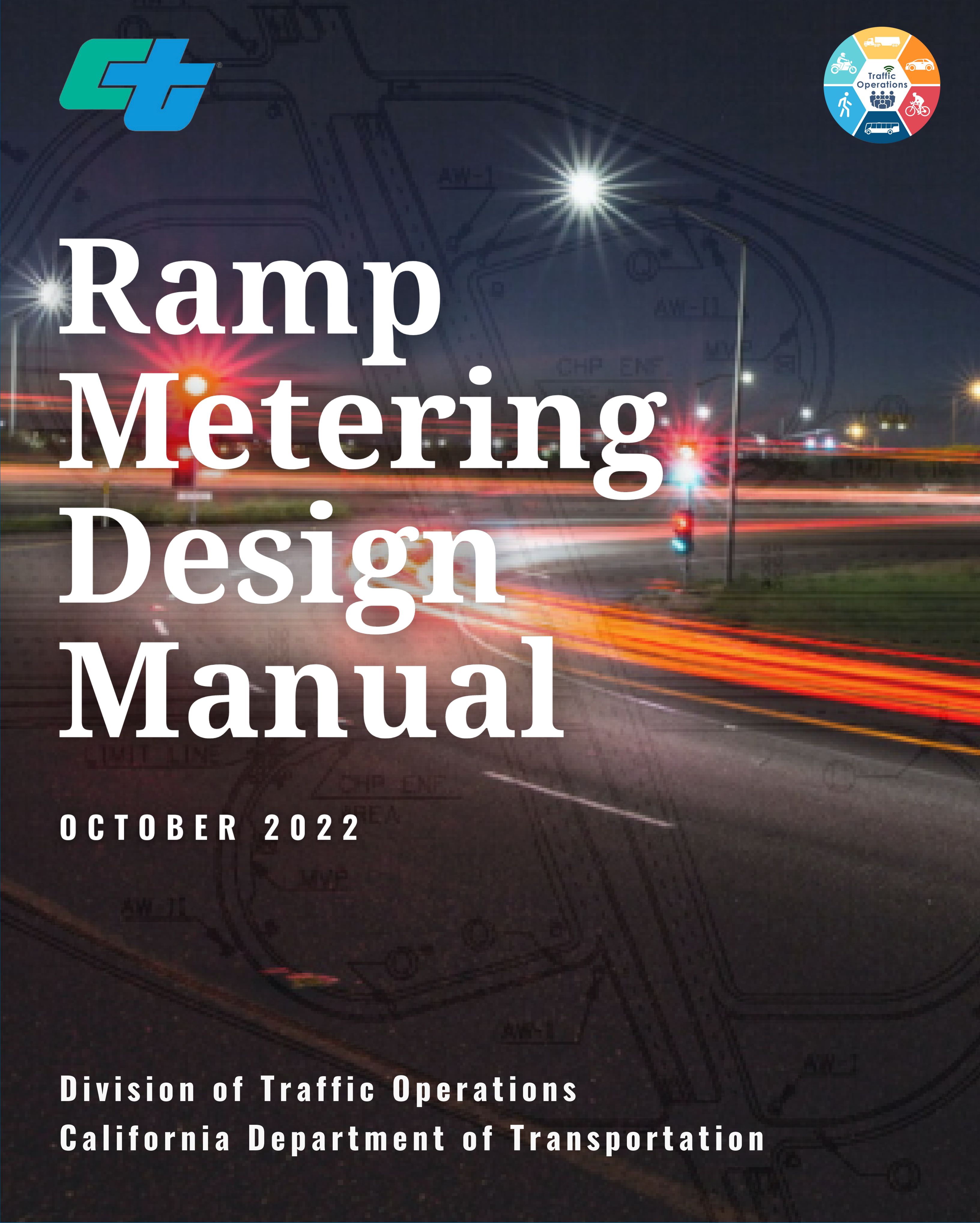


Ramp Metering Design Manual

OCTOBER 2022

Division of Traffic Operations

California Department of Transportation

Foreword

The California Department of Transportation (Caltrans) is committed to using ramp metering as an effective traffic management strategy. This manual was prepared for Caltrans by the Division of Traffic Operations for use on the California State Highway System (SHS). This manual establishes uniform policies and procedures to carry out the ramp meter design functions of Caltrans. This manual should be used in conjunction with the Caltrans *Ramp Metering Development Plan* (*RMDP*) and the Caltrans *Ramp Metering Operations Manual* (*RMOM*).

Ramp metering is a proven method of improving the efficiency of a highway system by eliminating or reducing freeway congestion. It is used to 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 *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. A ramp meter is one of the nine core transportation management system (TMS) units in the *State Highway System Management Plan* and are a significant historical investment by Caltrans and its partners. Many of these ramp meters may be approaching the end of their expected life cycles and may require replacement to ensure 90% of Caltrans TMS units are in good condition. There are a multitude of strategies to design ramp meters. In a state as diverse as California, several design considerations must be considered when designing a ramp meter. Standardizing ramp metering design provides several benefits such as statewide uniformity, consistency, and conformity along the SHS.

This document is an update to the 2016 Caltrans *Ramp Metering Design Manual* (*RMDM*). It is a living document that is meant to be periodically updated by a core team of seasoned transportation professionals. Proposed revisions for the next update should be emailed to the Chief, Office of Mobility Programs, Headquarters (HQ) Division of Traffic Operations.

The *RMDM* was prepared by Caltrans' divisions 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 meter facilities and is not intended to address operational topics, which are covered in the *RMOM*.

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 Chief, Office of Mobility Programs, HQ Division of Traffic Operations, and the 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 latest version of Deputy Directive (DD-35).

Ramp Metering Design Standards

Ramp metering design standards and guidelines 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* Chapter 21. For traffic-related design, 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 designs and procedures requires review and concurrence by 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.

Ramp Metering Procedural Requirements

The procedural requirements listed in this document are required courses of action to follow. These requirements are italicized throughout the document for emphasis.

Ramp Metering Policies

The ramp metering policies are developed to ensure statewide consistency in ramp metering design and operations. The policies are indicated using boxed text and placed in a separate paragraph for added emphasis. Deviation from these policies require the preparation of an “Exception(s) to Ramp Metering Policy Fact Sheet” (see Appendix B). Any deviation must be documented in the project file with supporting documentation. Concurrence with the proposed deviations from these policies shall be obtained from the Chief, Office of Mobility Programs, HQ Division of Traffic Operations, or the designated representative as early as possible in the project development process. An “Exception(s) to Ramp Metering Policy Fact Sheet” requires approval from the Deputy District Director of Traffic Operations.

Table of Contents

List of Metering Policies

List of Procedural Requirements

List of Tables

List of Figures

Chapter 1 Design of Metered Freeway Entrance Ramps and Connectors

1.1 Introduction

Caltrans latest version of Deputy Directive (DD-35) 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 the Caltrans *RMDP* shall include provisions for ramp metering. Projects designed for new or existing freeway segments without ramp meters but experiencing recurring traffic congestion, having a high frequency of vehicle collisions, or both, may consider adding ramp meters.

Geometric design of metered entrance ramps must comply with the standards contained in Caltrans' *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 *HDM* Index 103.2. For operational improvement projects, the design should be based on current peak hour traffic volume. 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-R3, "Complete Streets" and the Americans with Disabilities Act.

The entrance to a metered entrance ramp should accommodate the crossing of non-motorized traffic. 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 *HDM* Topic 201 for sight distance guidance.

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 rates 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 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. Increasing the vehicle occupancy requirement may be a solution to lessen the number of HOV lanes, if adding a second HOV preferential lane is inappropriate. Installing a second HOV preferential lane at metered freeway entrance ramps or connectors is generally not possible.

Ramp Metering Policy 1. Number of Metered Entrance Ramp Lanes

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

Approval for a ramp metering policy exception must be obtained prior to district approval of any project initiation documents such as Project Study Reports (PSR), Project Scope Summary Reports (PSSR), Design Engineering Evaluation Reports (DEER), Permit Engineering Evaluation Reports (PEER), or combined PSR and Project Reports (PR). See Appendix A for Deputy Directive 35–R1. See Appendix B for the "*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. Refer to the 1994 Highway Capacity Manual by the Transportation Research Board for the passenger-car equivalent conversion Table 3-3.

Table 1-1. Minimum Number and Type of Entrance Ramp Lanes (for Typical One Vehicle per Green Operations)

Peak Hour Lane Volume, VPH	Minimum Number of Metered Lanes	Figures
≤900	1 GP + 1 HOV(1)	1-1, 1-2, and 1-5
>900 but ≤1,800	2 GP + 1 HOV(1)	1-3, 1-4(2), and 1-6
>1,800	3 GP + 1 HOV(1)	(2)

[1]Increase the number of HOV lanes based on HOV demand.

[2]Obtain concurrence of the Caltrans *Chief, Office of Mobility Programs, HQ Division of Traffic Operations* 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).

Procedural Requirement 1-1. Number of Metered Entrance Ramp Lanes

Metered ramps shall have the number of lanes shown in Table 1-1. The number of lanes shown on the design plans require the review and concurrence by the Caltrans district traffic operations branch responsible for ramp metering. Document in the project file the reasons for deviating from the number of lanes specified by Table 1-1. Any proposed three-lane loop or four-lane entrance ramp requires the review and concurrence of the Caltrans Chief, Office of Mobility Programs, HQ Division of Traffic Operations, and approval by the 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

An important design consideration in ramp metering is to provide adequate storage for the metered vehicle queue upstream of the limit line.

Keep connecting local streets free from the adverse impacts of queue overspill by providing adequate vehicle storage within the metered ramp. Whenever feasible, ramp metering storage should be contained on the ramp by either widening or lengthening it.

Local streets at the at-grade intersection of metered ramps may be improved to provide more queue storage length when available storage length on the ramp is inadequate. Local street improvements may include widening the existing traveled-way at the at-grade intersection, adding turn pocket lanes to provide additional storage capacity for the appropriate ramp turning movements, restricting traffic volume entering the ramp, and adjusting the signal timing at upstream intersections of the metered ramp to help break up traffic platoons. These local street improvements require coordination with local agencies. Ultimately, corridor adaptive ramp metering may coordinate with local street signal systems.

New or reconstructed metered freeway entrance ramps or connectors should provide vehicle storage for 7% of the peak hour traffic volume that occurs within the design year.[1] The storage length for the GP and HOV lanes are calculated separately based on the GP and HOV peak hour traffic volumes that occur within the design year. When planning storage length for GP and HOV lanes, provide a minimum spacing of 29 feet, measured from the front of a vehicle to the front of the adjacent vehicle. For metered freeway entrance ramps or connectors with long downgrades or that serve significant

[1] Wang, Zhongren R., Queue Storage Design for Metered On-Ramps. *International Journal of Transportation Science and Technology,* Vol.2, No.1, 2013, pp. 47-64

percentages of trucks, buses, or recreational vehicles, a longer vehicle spacing may be more appropriate.

For existing ramp metering, calculate the minimum vehicle storage length required to ensure storage adequacy for the current maximum traffic volume that arrives within the 5, 6, or 15-minute period of the peak hour volume and the existing metering discharge rate. Apply Appendix D, "Arrival-Discharge Chart Method" to determine the maximum queue length expected at existing ramps or connectors due to metering. The "Arrival-Discharge Chart Method" in Appendix D is not to be used for storage length design of new metered freeway entrance ramps or connectors.

The GP lane demand is the total ramp peak hour demand minus the HOV demand. For example, for a metered freeway entrance ramp or connector with two GP lanes and one HOV lane, if the total peak hour demand is 1,200 vehicles and 15% of those are HOV traffic, then the minimum storage length necessary for each of the two GP lanes is the following: (1,200 vehicles) (total peak hour traffic) – (1,200 vehicles x 15%) (percent of HOV preferential traffic) x 7% (percent of vehicle storage required) x 29 feet / vehicle (required storage length per vehicle) / 2 GP lanes = 1,035 feet for each GP lane. The two GP lanes are assumed to be used equally.

$$100\% - 15\% \text{ HOV volume} = 85\% \text{ GP volume}$$

$$\frac{7\% \times (1{,}200 \text{ veh}) \times (85\% \text{ GP vol}) \times (29 \, {}^{\text{ft}}/_{\text{veh}})}{2 \text{ GP lanes}}$$

$$\text{Mimimum GP storage length} = 1{,}035 \, {}^{\text{ft}}/_{\text{lane}}$$

The HOV demand may vary widely, thus current and project specific HOV demand information is necessary. The minimum storage length necessary for HOV lanes is calculated using the same methods used for the GP storage length calculation. For example, if the total peak hour demand is 1,200 vehicles and 15% of those are HOV traffic, then the minimum storage length necessary for one HOV lane is the following: (1,200 vehicles x 15%) (total number of HOVs in the peak hour) x 7% (percent of vehicle storage required) x 29 feet / vehicle (required storage length per vehicle) = 365 feet.

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

$$\text{Mimimum HOV storage length} = 365 \, {}^{\text{ft}}/_{\text{lane}}$$

Generally, a metered freeway entrance ramp or connector typically has less HOV traffic than GP traffic. The metering signal timing of HOV lanes is generally set at a faster rate than the metering signal timing of GP lanes to provide preferential treatment. This does not necessarily mean that the total length of a metered HOV lane is shorter than the GP lanes, because the calculated minimum storage length is only one factor to consider in sizing the HOV lane. In fact, the HOV lane(s) should be designed to match the length of the adjacent GP lane(s). This allows earlier access to the HOV lane and discourages the HOV traffic from queuing in the GP lane(s). The storage length adequacy for metered HOV lanes is seldom an issue.

Procedural Requirement 1-2. Queue Storage Length Design

Storage length design requires the review and concurrence by the Caltrans district traffic operations branch responsible for ramp metering. In the project file for new or reconstructed metered freeway entrance ramps or connectors, document the reasons for deviating from providing storage for 7% of the metered vehicles. Document in the project file the reason for deviating from providing storage length for existing metered ramps, the reasons for deviating from the minimum storage length of the current maximum vehicle volume that arrives within the 5-, 6-, or 15-minute period of the peak hour volume, and the discharge rate as determined in the arrival-discharge chart for existing metered freeway entrance ramps or connectors.

1.5 Stopping Sight Distance

In addition to queue storage length, the stopping sight distance to the back of the vehicles upstream of the limit line should also be included in the length of a metered entrance ramp. The stopping sight distance is the stopping distance required for approaching traffic to decelerate and stop clear of the back of traffic queue. Use the design speed of the entrance ramp or the connecting roadways as the approach speed to the back of traffic queue. Refer to *HDM* Topic 201 for more information on how to determine stopping sight distance.

1.6 Acceleration Distance

The ramp metering acceleration distance is the distance downstream from the limit line that stopped vehicles need to accelerate to reach the merging speed with the freeway mainline traffic. It may include the lane-drop taper (transition) and auxiliary lane length up to the beginning of the merging taper.

An auxiliary lane of at least 300 feet long shall be provided beyond the ramp convergence point. A longer auxiliary lane should be provided based on vehicle types, demand volume, and geometry. See *HDM* Index 504.3(2), "Ramp Metering."

As specified in the *American Association of State Highway and Transportation Officials'* (*AASHTO*) 2018 *A Policy on Geometric Design of Highways and Streets*, Chapter 10, "Grade Separations and Interchanges," the entrance ramp traffic merging speed should be at or near the freeway speed. The acceleration value used should be commensurate with the selected design vehicles. Specifically, Table 10-3 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 Table 10-4 provides speed change lane adjustment factors as a function of grade. Refer to *HDM* Chapter 500 for detailed geometric design guidance related to lane-drop taper (transition), auxiliary lanes, and merging taper.

1.7 Limit Line Location

The limit line is where metered vehicles stop for a red signal and wait for the metering signal head to turn green 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 stopping sight 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, "*Acceleration Distance*" on how to calculate the required acceleration distance.

For multi-lane metered entrance ramps, the location of the limit line must be considered when designing 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.

Procedural Requirement 1-3. Limit Line Location

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 and vehicle miles traveled. All metered ramps shall include HOV lanes and all HOV lanes should be metered as directed by Caltrans latest version of Deputy Directive (DD-35). One of the benefits of metering every HOV lane is matching the merging speed of HOV and GP traffic downstream of the limit line. HOVs that meet the occupancy requirement have an incentive to utilize HOV preferential lanes with lower volume than GP lanes, thus saving time. Tailor ramp HOV lanes to the unique conditions present at each ramp (for example, faster metering rates for carpool, vanpool, and transit riders).

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. In addition, 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. To avoid trapping GP traffic into an HOV preferential lane, the pavement marking at the ramp entrance should guide motorists into the GP lane(s). Refer to Chapter 3, "Signing and Pavement Markings," for HOV preferential lane signs and pavement markings. When there is an expectation that queued vehicles will block access to the HOV preferential lane, consider providing direct or separate access.

Typically, place the HOV lane on the left side of the ramp, however traffic demand and operational characteristics may dictate otherwise. Placing the HOV lane on the right is acceptable, but road users generally expect HOV lanes to be on the left. Placing the HOV lane in the middle lane(s) (for three or more metered lanes) is not permitted as it does not allow for signage identifying the HOV lane.

In general, the vehicle occupancy requirement for metered entrance ramp and connector HOV preferential lanes is two or more persons per vehicle (except for motorcycles or qualifying clean air vehicles with decals). At some locations, a higher vehicle occupancy requirement may be necessary because the occupancy should be based on the HOV demand. HOV preferential lane occupancy should be coordinated with other facilities in the vicinity. Increasing the vehicle occupancy requirement may be a solution to lessen the number of HOV lanes, if adding a second HOV preferential lane is inappropriate. Installing a second HOV preferential lane at metered freeway entrance ramps or connectors is generally not possible.

See Chapter 3, "Signing and Pavement Markings" figures 3-4 to 3-7 for typical HOV lane signing, pavement markings, and details of the typical access opening to the HOV lane.

Procedural Requirement 1-4. HOV Preferential Lanes

Design of the HOV preferential lane, including the occupancy requirement for 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 for the following situations: (1) if the existing HOV preferential lane is under-utilized, (2) there is a need for additional queue storage for the GP lanes, or (3) an alternate entrance ramp HOV preferential lane is available within 1.5 miles.

Procedural Requirement 1-5 Converting HOV Preferential Lanes to GP Lanes

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 shall be concurred with by the Caltrans Chief, Office of Mobility Programs, HQ Division of Traffic Operations, or the designated representative and shall be approved by the deputy district director of traffic operations.*

1.10 Enforcement Areas and Maintenance Vehicle Pullouts

Ramp Metering Policy 2. Enforcement Areas and Maintenance Vehicle Pullouts (a)

A paved enforcement area shall be provided at each new or reconstructed metered entrance ramp or connector.

Enforcement areas are used by 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.

Procedural Requirement 1-6. Enforcement Areas and Maintenance Vehicle Pullouts (a)

Contact the CHP Area Commander and CHP Special Projects (located at HQ in Sacramento) 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.*

Ramp Metering Policy 3. Enforcement Areas and Maintenance Vehicle Pullouts (b)

A paved maintenance vehicle pullout (MVP) shall be provided at each new or reconstructed metered entrance ramp or connector.

A paved MVP provides a convenient location for maintenance and operations personnel to access controller cabinets. The MVP should be placed 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. See *HDM* Index 107.2, "Maintenance and Police Facilities on Freeways" for MVP design and Caltrans *Revised Standard Plan Sheet H9*, "Landscape Details" for the plan view and cross-sectional details of a typical MVP on level grade. For MVPs in an excavated area, modification of the MVP layout shown in the *Standard Plans* may be required.

Procedural Requirement 1-7. Enforcement Areas and Maintenance Vehicle Pullouts (b)

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 should also be metered when feasible. 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)(d). Since freeway-to-freeway connectors operate at higher speeds and volumes, sight distances, and queue storage, lengths need to be reviewed accordingly. In addition, at least two sets of advance warning devices (typically blank-out signs and flashing beacons) shall be provided. When planning to meter a connector, discuss with the Caltrans Chief, Office of Mobility Programs, HQ Division of Traffic Operations, and the HQ Design Coordinator or Reviewer as early as possible. Issues of concern are stopping sight distance, potential need to widen shoulders if the sight distance is restricted, and the potential for queuing back onto the approach freeway.

Unless noted otherwise, freeway-to-freeway connector metering criteria 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. For restrictive condition ramp metering (one GP lane) freeway entrance ramp slip and loop ramp metering single-lane entrance ramps, see *HDM* Figures 504.3C and 504.3D.

Refer to *HDM* Index 504.4 for more guidance on freeway-to-freeway connectors.

Ramp Metering Policy 4. Metered Freeway-to-Freeway Connectors

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

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

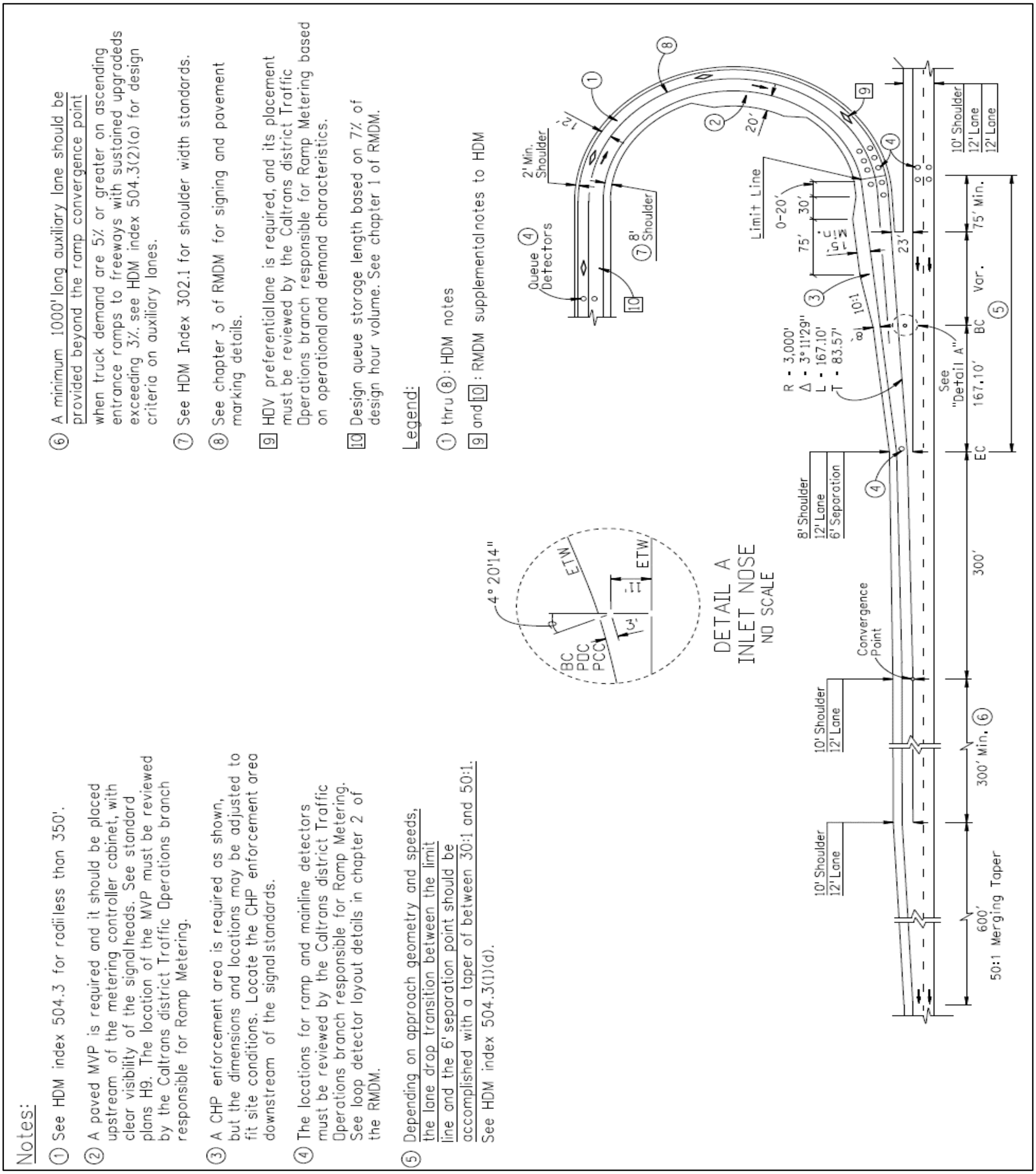


Figure 1-2. Typical 2-Lane Metered Successive Freeway Entrance Ramps (1 GP Lane + 1 HOV Preferential Lane)

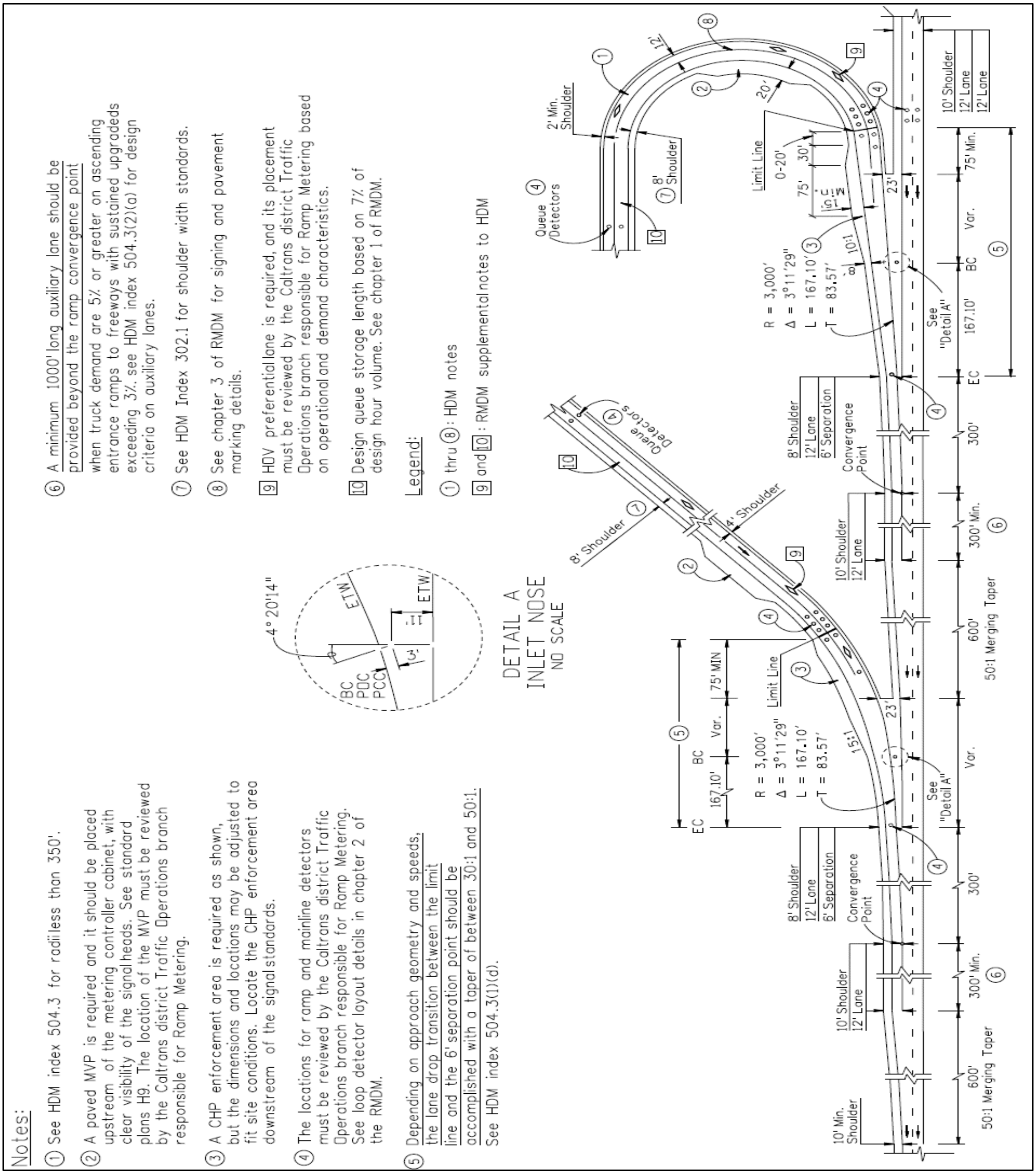


Figure 1-3. Typical 3-Lane Metered Freeway Diagonal Entrance Ramp (2 GP Lanes + 1 HOV Preferential Lane)

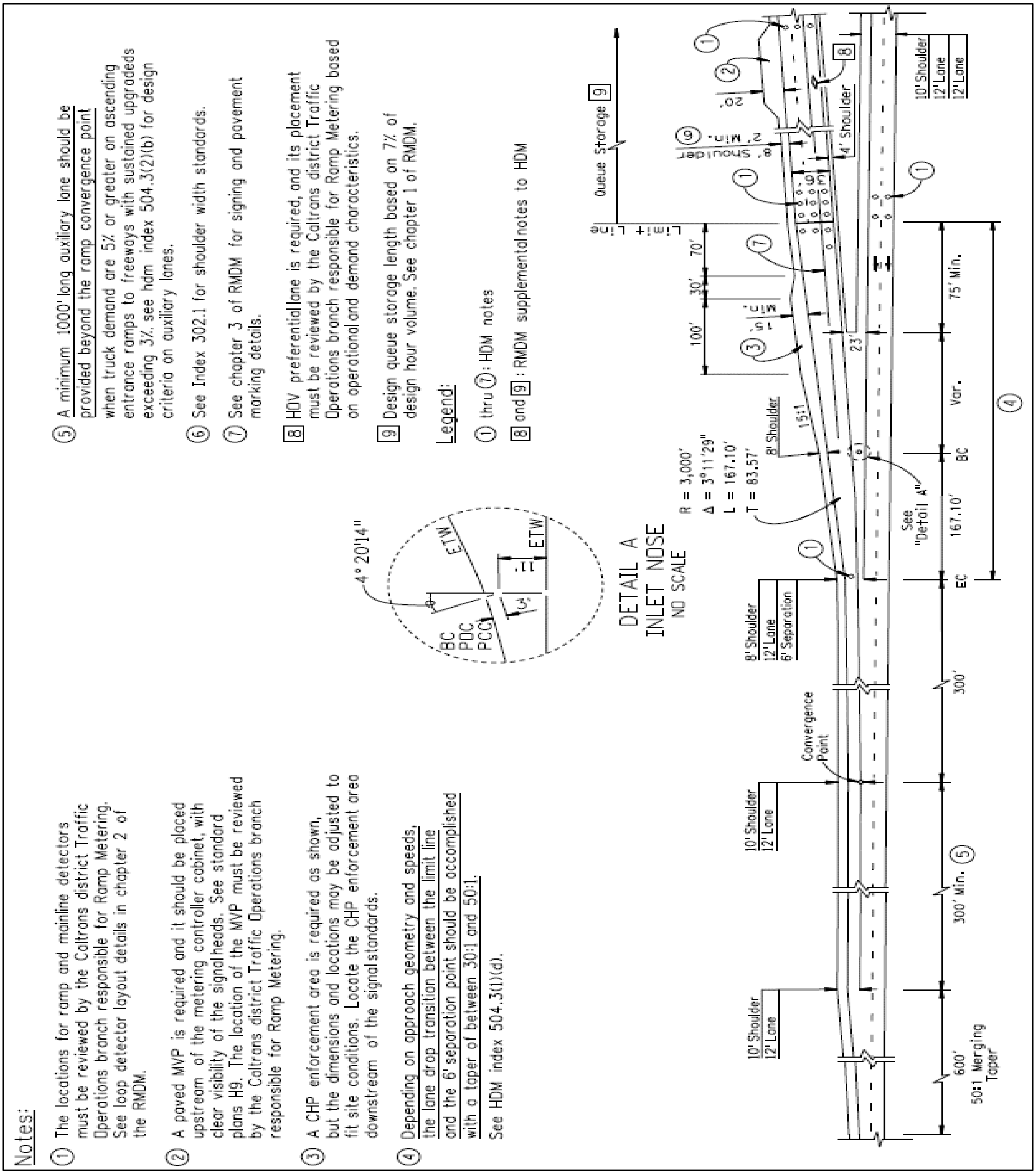


Figure 1-4. Typical 3-Lane Metered Freeway Loop Entrance Ramp (2 GP Lanes + 1 HOV Preferential Lane)

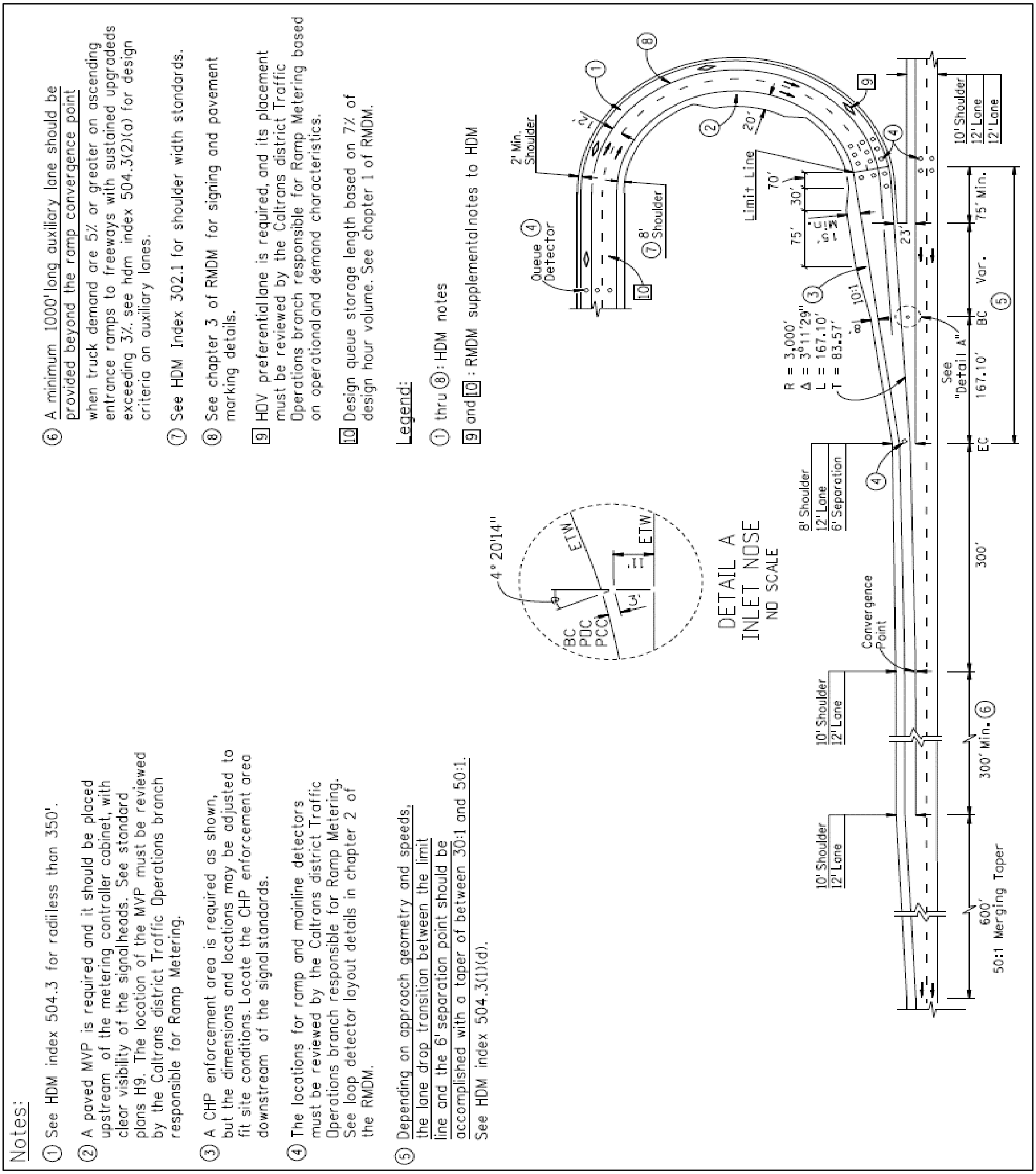


Figure 1-5. Typical 2-Lane Metered Connector (1 GP Lane + 1 HOV Preferential Lane)

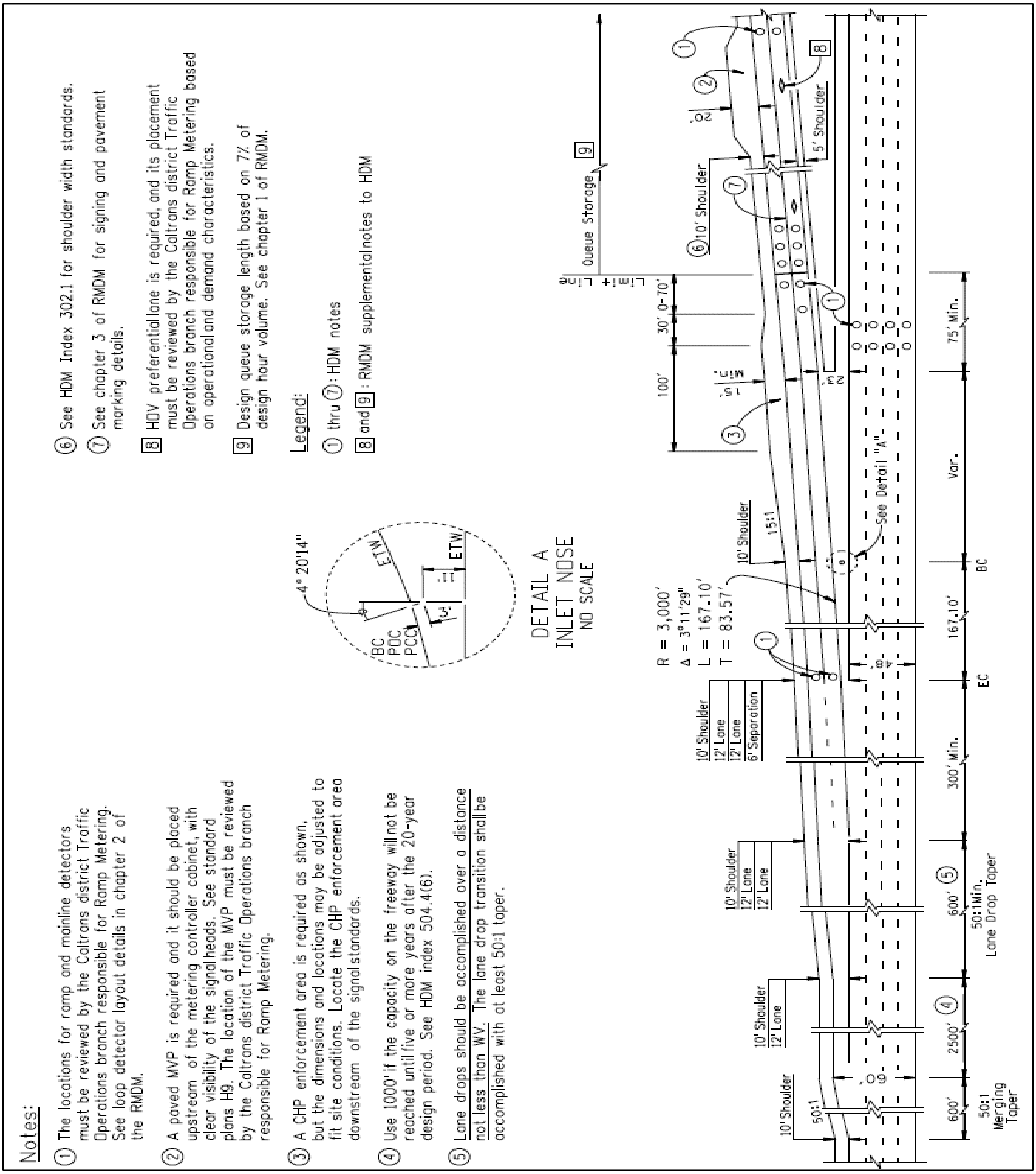
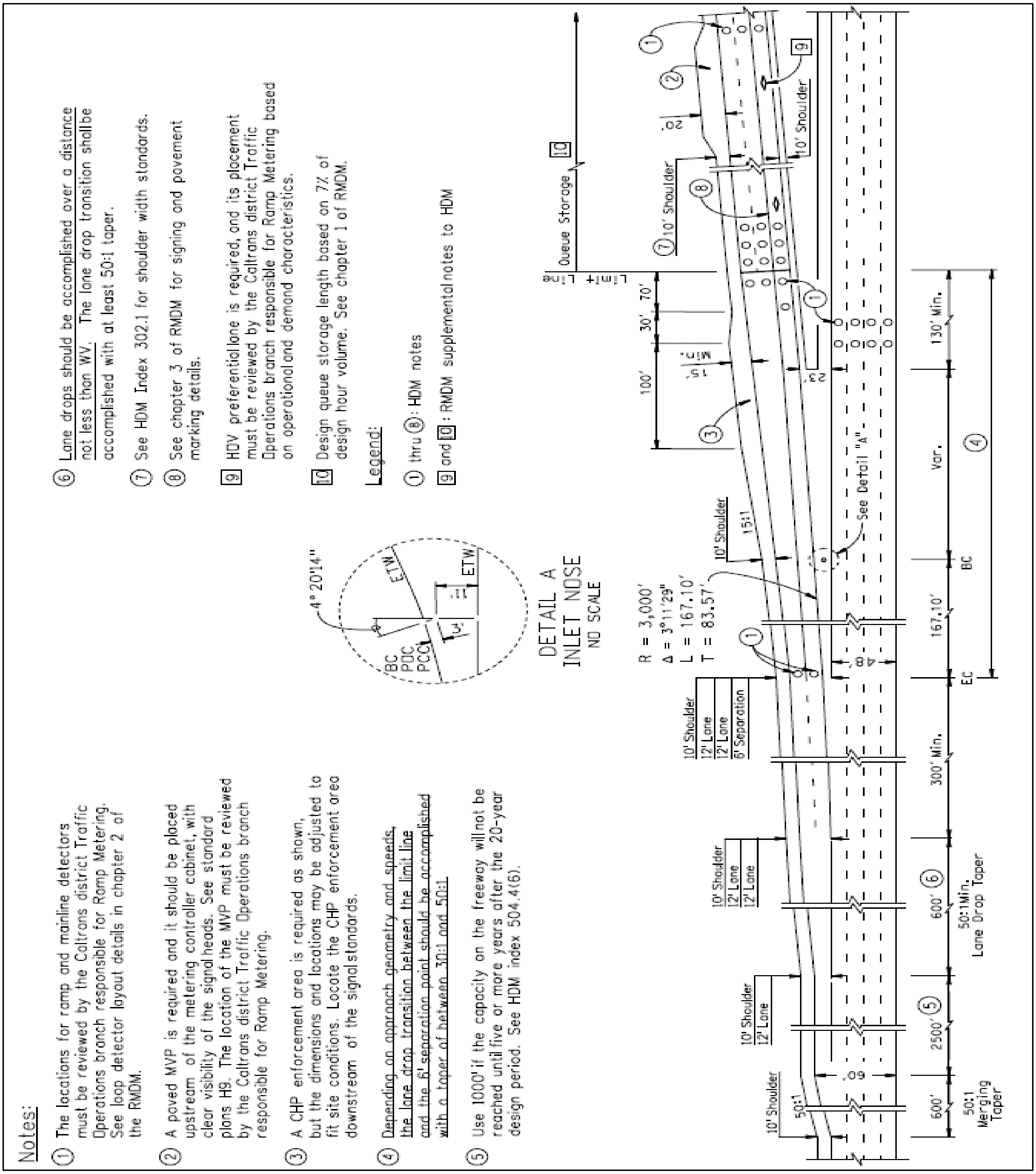


Figure 1-6. Typical 3-Lane Metered Connector (2 GP Lanes + 1 HOV Preferential Lane)



Chapter 2 Hardware and System Integration

2.1 Introduction

At a minimum, ramp metering hardware elements shall include the following: 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) central system. Theft prevention strategies to protect ramp metering field hardware elements, including conductors, shall be considered in the project development process.

Procedural Requirement 2-1. Hardware and System Integration

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 avoid exposing field personnel to live traffic. 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 of 2.5 seconds (see Section 2C.05, "Placement of Warning Signs" of the *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 (such as ramps with long entrance lengths, steep grades, or limited stopping sight distances) or metering operational characteristics (such as 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 may 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 head is limited.

Type 1 standards should be located a minimum of 1 foot downstream of the trailing edge of the limit line and 3 feet offset from the outside edge of the shoulder. A mast-arm standard should be clearly visible and placed a minimum of 70 feet downstream of the limit line on the right side of the entrance ramp to minimize knockdowns, but no more than 120 feet. Rotating mast-arm support structures should be considered to minimize maintenance lane closures.

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 indications 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 or 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 per metered lane. Align the signal heads on the mast arm with the center of each traveled way lane at the limit line. 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 or 12-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 should be provided when recommended by a traffic engineer to illuminate the limit line during pre-dawn or post-dusk hours. Lighting standards, such as Type 15, may be used. Refer to the Caltrans *Electrical Systems Design Manual* for typical ramp meter design plan sheet details.

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 if it provides the same level of accuracy, precision, cost-effectiveness, and reliability.

Procedural Requirement 2-2. Detectors (a)

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.

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.

Procedural Requirement 2-3. Detectors (b)

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, dual 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 approximately at three quarter point of the entrance ramp from the limit line. The queue detector identifies a potential ramp metering queue overflow.

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.

Procedural Requirement 2-4. Entrance Ramp Queue Detectors

For additional queue detectors and opposite side mainline lane 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 to capture all entrance ramp vehicles entering the freeway. When a district recommends 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 a collector-distributor road design.

2.3.8 Detectors at Metered Connector

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 metered entrance ramp, a controller cabinet shall be installed to house the traffic controller(s), input files, detector cards, power distribution assembly, load switches, and appropriate communications equipment. All associated mainline, entrance ramp, and exit ramp loop detector cables shall terminate into the controller cabinet terminal block according to the layout plan. 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 equipped with 120-volts alternating current 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 meeting 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 in areas subject to water runoff or prone to flooding. Refer to the *CA MUTCD*, the Electrical System Design Manual, 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.

Procedural Requirement 2-5. Controller Cabinets

The 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, cellular, microwave, radio frequencies, telephone landlines, and leased wireless systems are all possible communication 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. An interconnect between a Caltrans signal cabinet and ramp metering cabinet should be placed to extend network to include off-ramp intersection communications, ramp meter versus signal coordination, and integrated corridor management.

Procedural Requirement 2-6. Communications (a)

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.

Procedural Requirement 2-7. Communications (b)

The telephone service requirements and the location require the review and concurrence of the Caltrans district traffic operations branch responsible for electrical systems, in coordination with the affected specific telephone provider involved.

Procedural Requirement 2-8. Communications (c)

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 field element network management. Network security requires that all field elements communicate with the central system via a transmission control protocol 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

Ramp Metering Policy 5. Advance Warning Devices

Advance warning devices (signs with beacons) shall be provided at metered freeway entrance ramps.

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 Freeway Entrance Ramps

To alert approaching motorists when ramp meters are in operation, two advance warning devices are typically used.

- AW-I is the "RAMP METERED WHEN FLASHING" (W3-8) warning sign with an amber-colored flashing beacon, described in *CA MUTCD* Section 2C.37, "Advance Ramp Control Signal Signs (W3-7 and W3-8)." The beacon flashes whenever the downstream ramp control signal is cycling.

- AW-II is the "RAMP METER AHEAD" (W3-7) warning sign with an amber-colored flashing beacon. The beacon flashes whenever the downstream ramp control signal is cycling.
- See Figure 2-12 for installation details of these two advance warning devices.

At the entrance to a metered entrance ramp, at least one advance warning device—the AW-I or AW-II— shall be positioned facing each direction of traffic entering the ramp. Additional AW devices may be deployed further upstream of entrance to the ramp to facilitate route diversion. AW devices may be provided at any location between the entrance to the ramp and the limit line to alert approaching motorists of the presence of downstream metering signals or the presence of the ramp metering traffic queue.

Procedural Requirement 2-9. Advance Warning Devices for Metered Freeway Entrance Ramps

The location, number, and type (if applicable) 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 Connectors

Ramp Metering Policy 6. Advance Warning Devices for Metered Freeway Connectors

Advance warning activated blank-out (ABO) signs with flashing beacons shall be provided at metered freeway connectors.

To alert approaching motorists when metered freeway connectors are in operation, two advance warning devices are typically used.

- AW-III is the "METER ON" (W88-2(CA)) advanced warning sign with two amber-colored flashing beacons, described in the *CA MUTCD* Section 2C.37. AW-III (modified) is the “METER ON” sign supplemented with the following two messages: the first message “METER ON” informs the motorist that the freeway connector is metered, and the second message provides the freeway name and direction that is at the end of the metered freeway connector. A W88-3(CA) ABO can be installed in place of the W88-2(CA) ABO when more complete travel information is to be conveyed to the motorist. For example, as shown in Figure 2-13, “210 WEST METER ON” (W88-3(CA)) indicates that the connector to westbound Route 210 is metered. Supplement the W88-3(CA) ABO with two 12-inch diameter amber flashing beacons with back-plates. The beacons flash whenever the downstream ramp control signal is cycling.

- AW-IV is the "PREPARE TO STOP" (W89(CA)) advanced warning sign with two amber-colored flashing beacons described in *CA MUTCD* Section 2C.37. The beacons flash whenever the downstream ramp control signal is cycling.
- See Figures 2-12 and 2-13 for the location and installation details of these advance warning signs and beacons.

The AW-III or AW-III (modified) device is installed upstream of the entrance to a metered connector, alongside or overhead of the freeway. The devices should be located a minimum 500 feet upstream of the gore point as shown in Figure 2-13. 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 connector exit gore area. Additional AW-IV or AW-II devices may be deployed further downstream on the connector. The minimum spacing between the last AW-IV 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 no less than 1,000 feet. If the queue extends upstream of the AW-IV device, its location should be adjusted, or an additional AW-IV device should be installed upstream of the end of the queue. The spacing between the metering signal—or end of the metered queue—and additional AW-IV device combinations is project specific and dependent on design speed, roadway curvature, sign visibility, and traffic volume. See *HDM* Topic 201 for sight distance calculations.

When a single lane enters the metered freeway connector, install the AW-III or AW-III (modified) device on the right side of the freeway lane exiting to the connector, mounted on ground mounted posts or overhead mast-arm structures. When multiple lanes enter the metered entrance connector, install the AW-III or AW-III (modified) ABO device on overhead mast-arm structures above the freeway lanes exiting to the metered freeway connector.

For a single lane metered freeway connector proper, attach the AW-IV device to ground-mounted posts on the right side of the connector, outside of the roadbed. For a two-lane metered freeway connector proper, attach the AW-IV device to posts on both sides of the freeway connector proper. For a freeway metered connector proper with two or more metered lanes with limited visibility to the AW-IV device, attach the device to overhead structures.

Procedural Requirement 2-10. Advance Warning Devices for Metered Freeway Connectors

Supporting structures other than those shown in Caltrans' latest Standard Plans require the review and approval by the Caltrans Division of Engineering Services. The placement and number 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 shall be added to the TMC central system and propagated to the Caltrans HQ TMS Inventory Database. Real-time data acquisition from the new locations shall be tested and integrated into the user interface/map display of the central systems 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, district guidelines, and specifications.

Procedural Requirement 2-11. Temporary Entrance Ramp Meters

The use of a 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

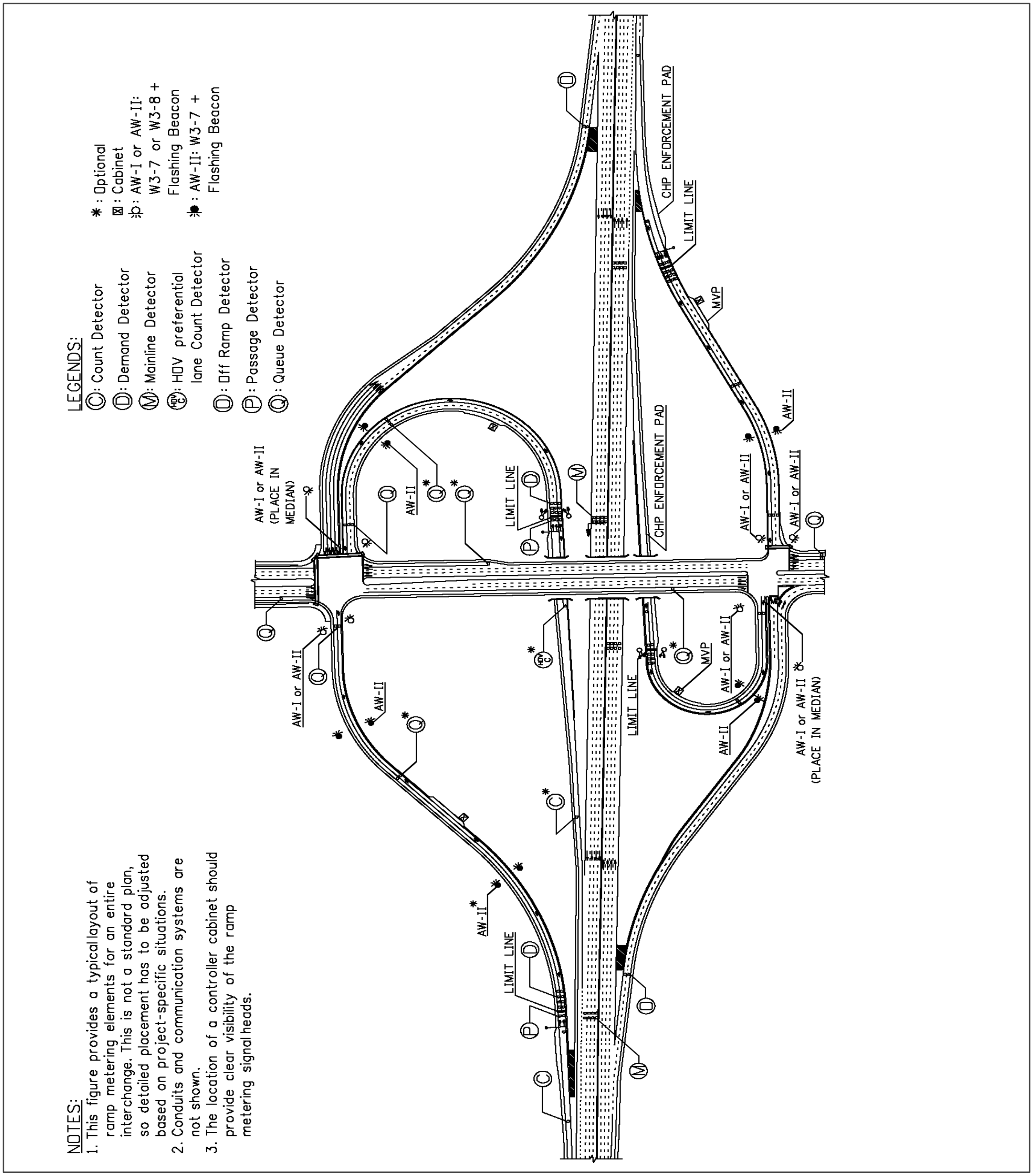


Figure 2-2. Typical Layout of Ramp Metering Elements at a Full-Cloverleaf Interchange

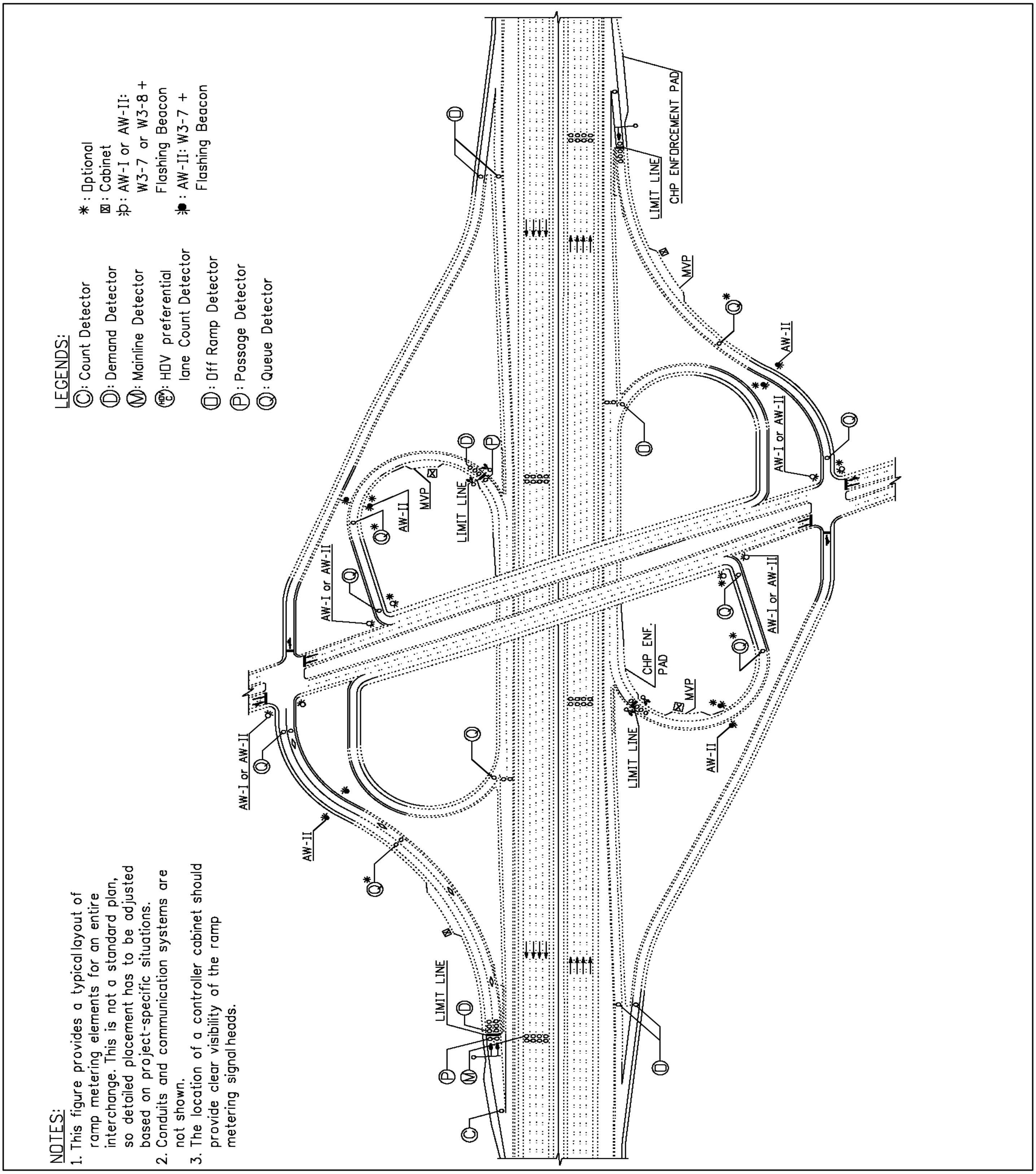


Figure 2-3. Typical Type 1 Signal Standard Installations

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.
6. Signal heads SHALL NOT be provided with reflective borders.

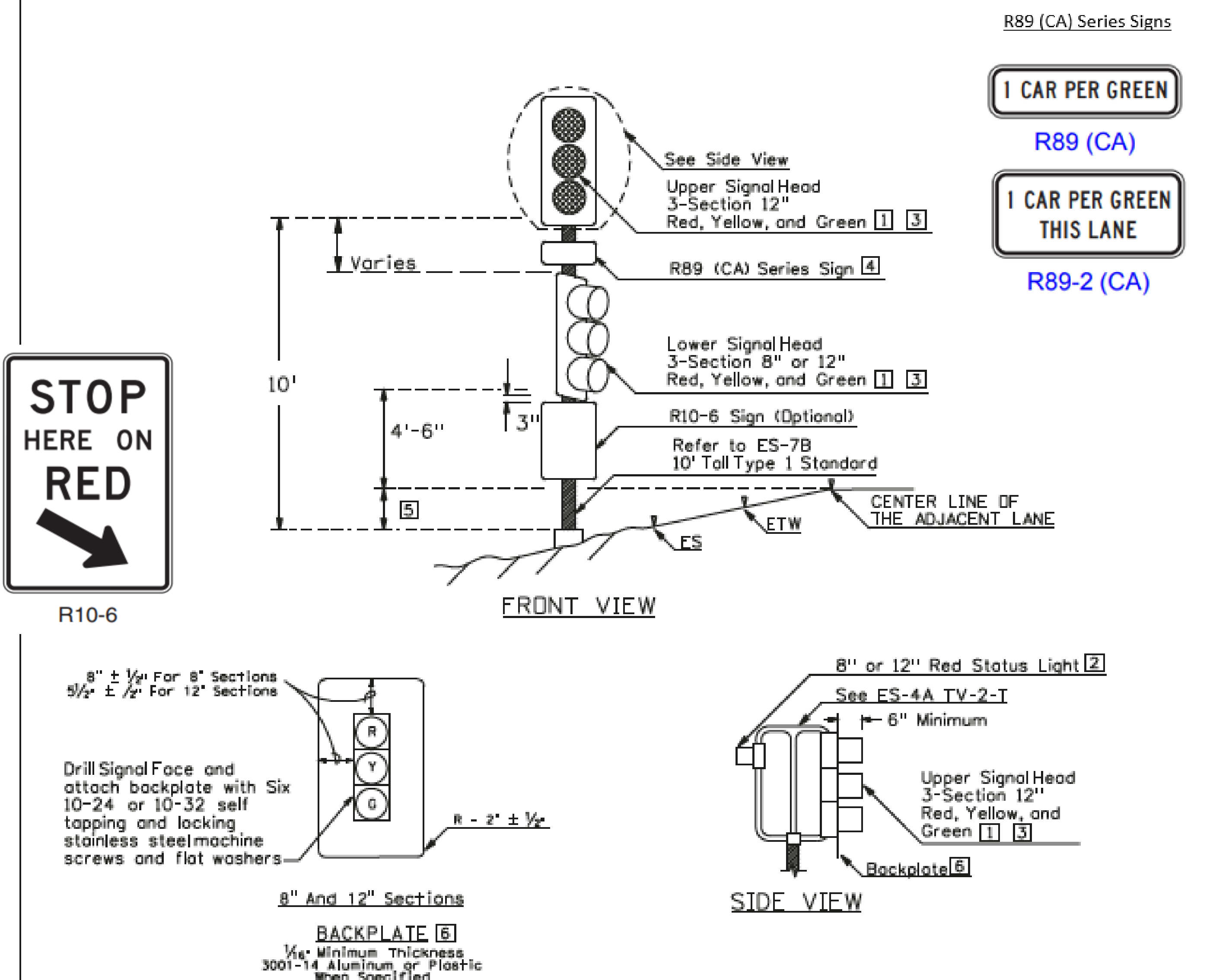


Figure 2-4. Typical Mast-Arm Signal Standard Installations

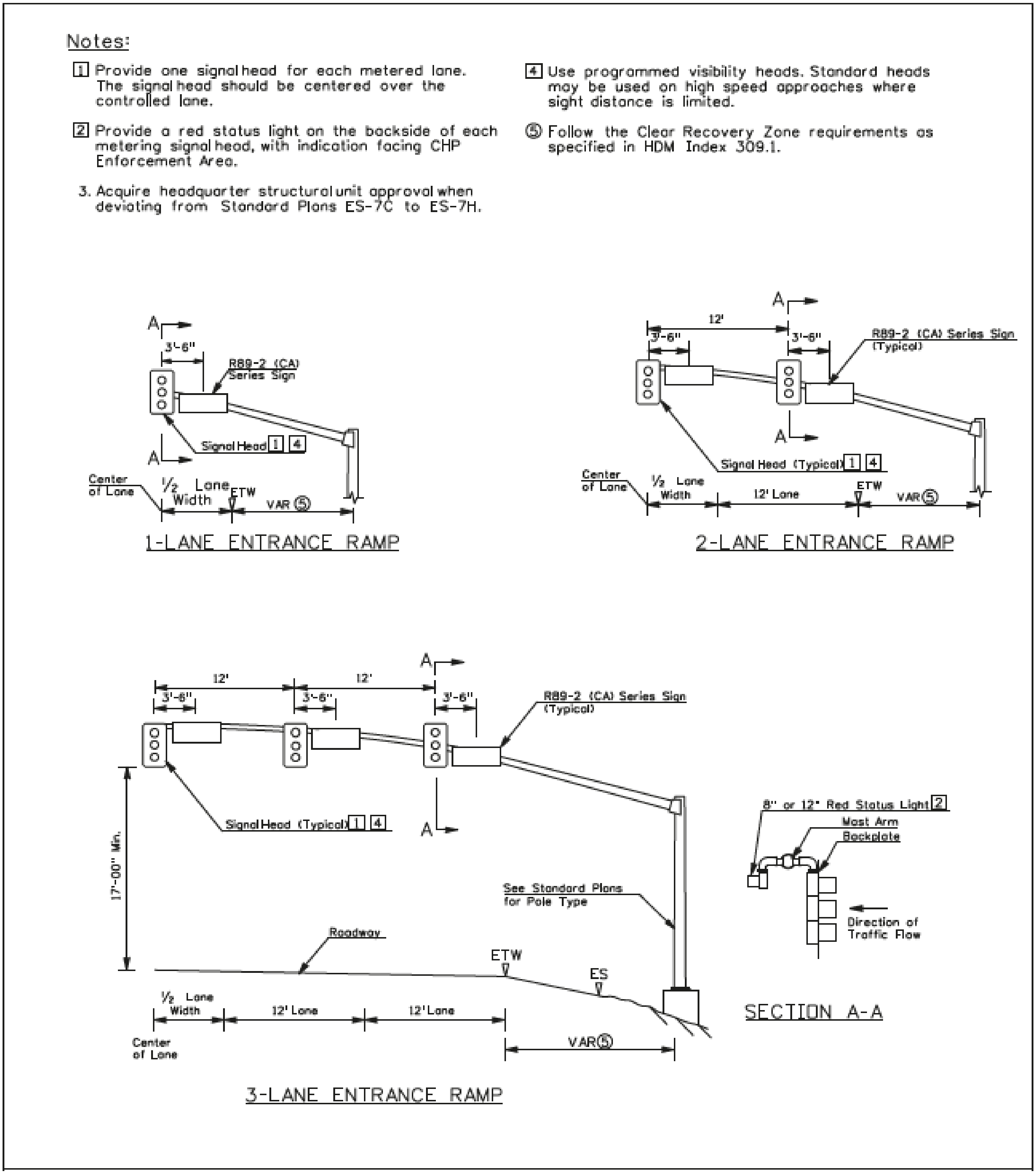


Figure 2-5. Typical Signal Standard Placement Detail at Loop Entrance Ramps

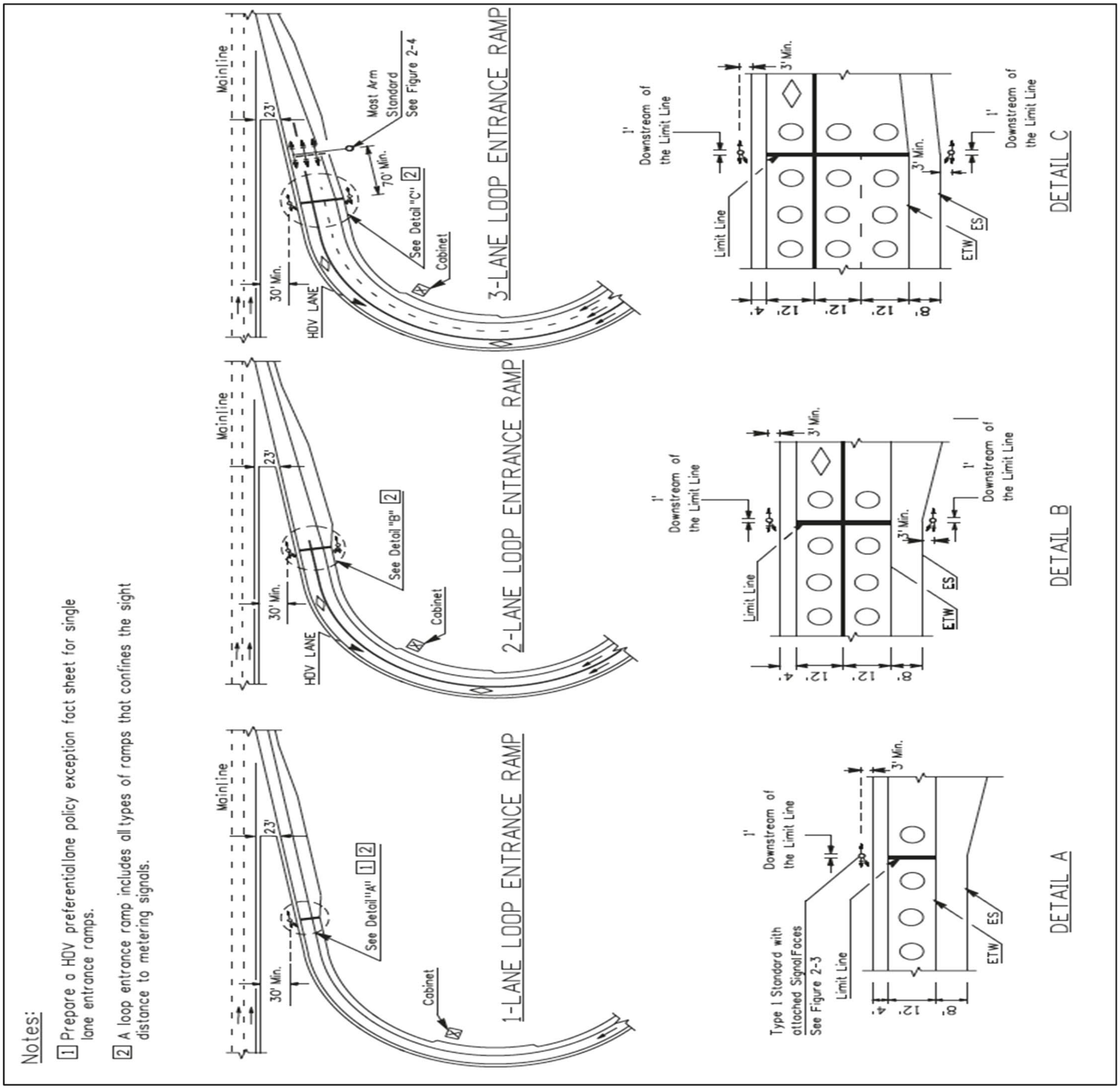


Figure 2-6. Typical Signal Standard Placement Detail at Diagonal Entrance Ramps

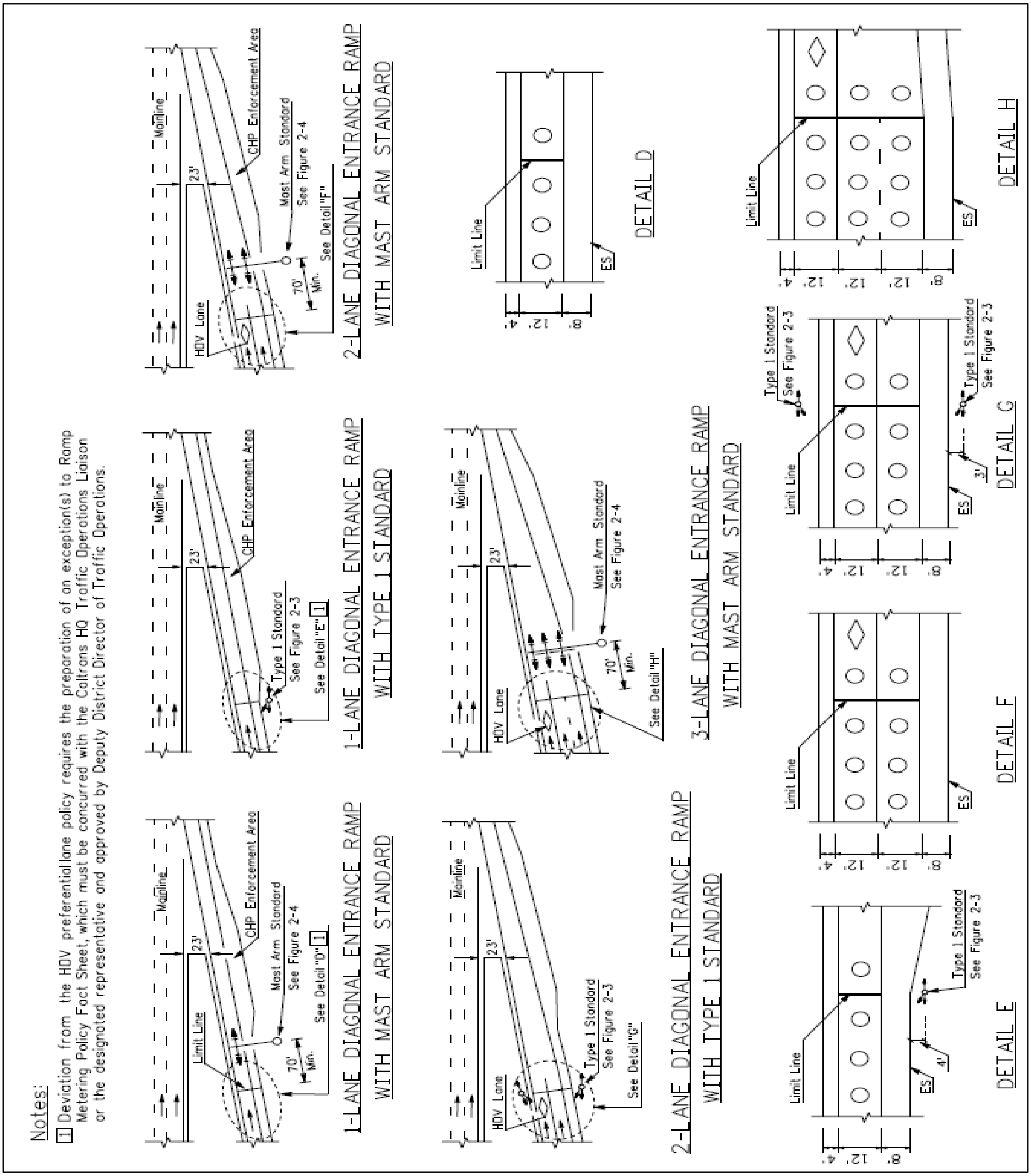
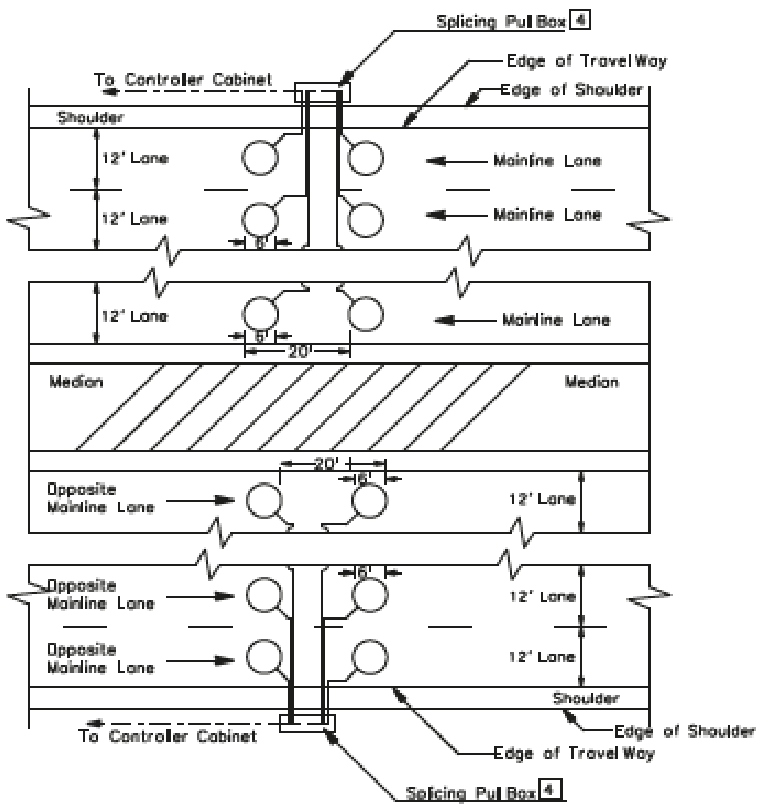


Figure 2-7. Typical Detector Layout for Freeway Mainline

Notes:

1. Detector Loops may be either Type A or Type E centered in each lane. Use 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

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 ¾ point of an entrance ramp, measured from the ramp limit line. 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) : Type A or Type E Count Detector

(D) : Type A or Type E Demand Detector

(P) : Type A or Type E Passage Detector

(Q) : Type A or Type E Queue Detector

(HOV C) : Type A or E HOV preferential lane Count Detector

EC : 6-Ft. Separation point

✱ : Optional

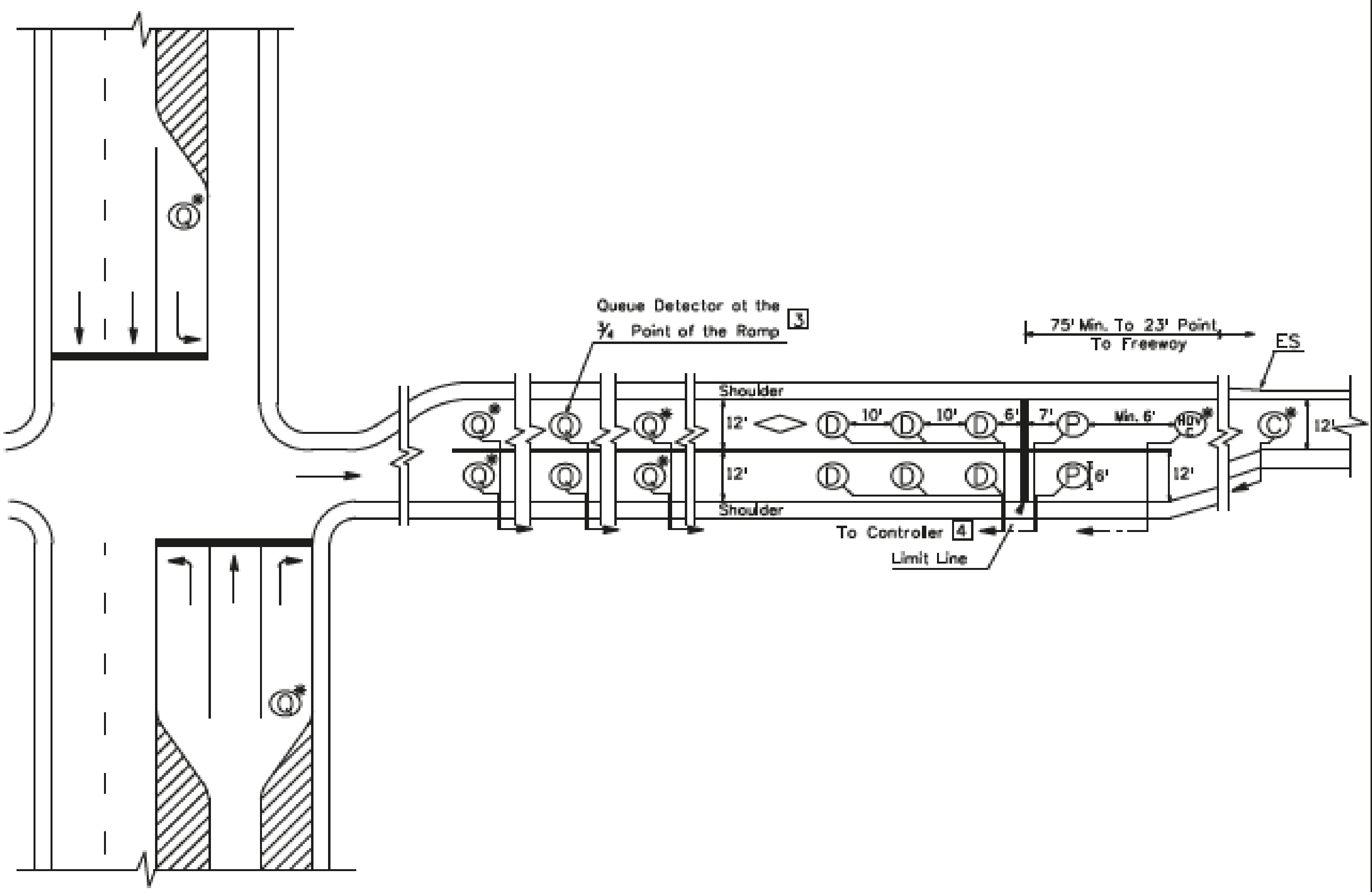


Figure 2-9. Typical Detector Layout for a Three-Lane Entrance Ramp

Notes:

1. The Detector Loops may be either Type A or Type E 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 3/4 point of an entrance ramp, measured from the ramp limit line. 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) : Type A or Type E Count Detector
- (D) : Type A or Type E Demand Detector
- (P) : Type A or Type E Passage Detector
- (Q) : Type A or Type E Queue Detector
- (HOV C) : Type A or E HOV preferential lane Count Detector
- EC : 6-Ft. Separation point
- ✱ : Optional

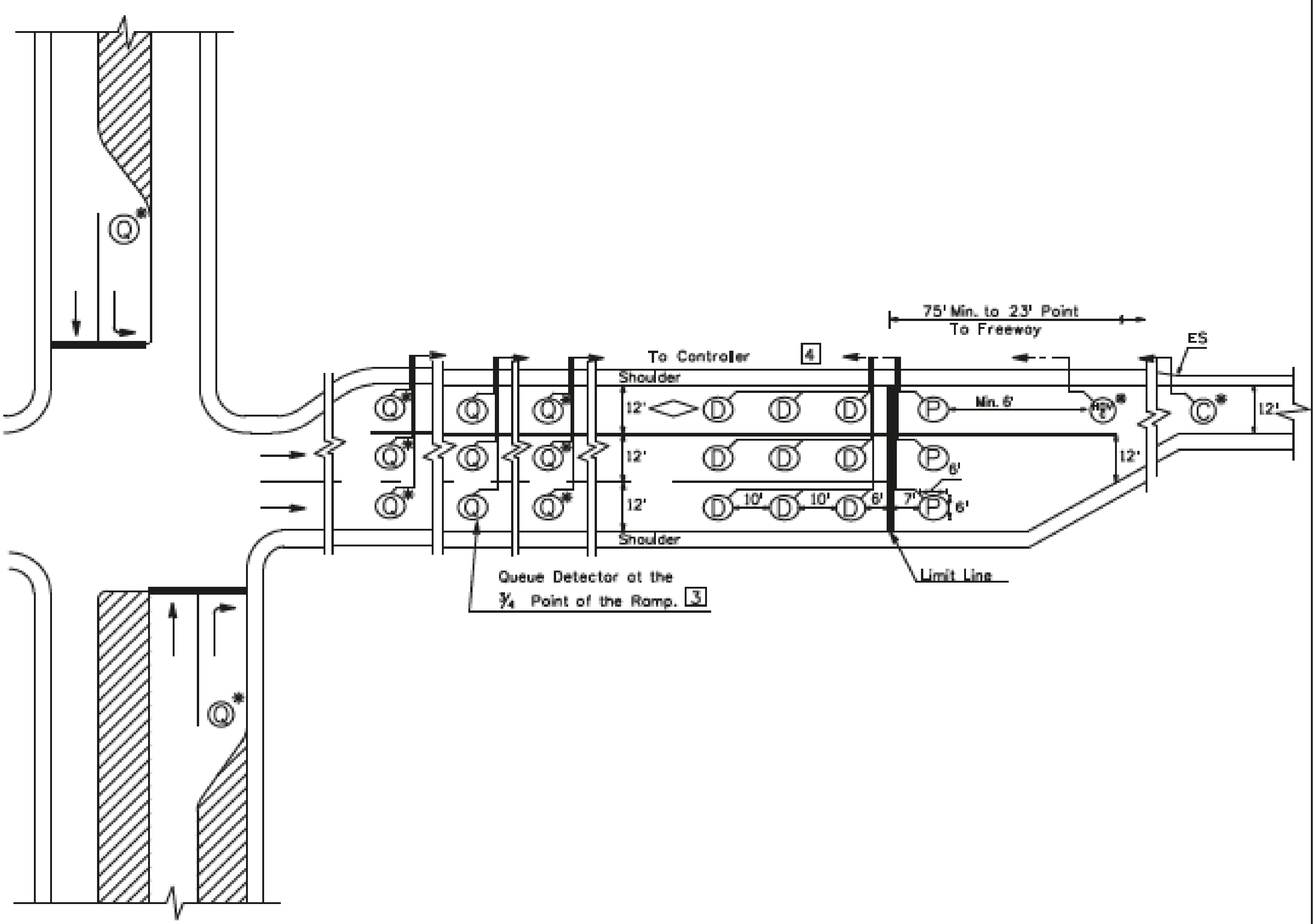


Figure 2-10. Typical Detector Layout for an Exit Ramp

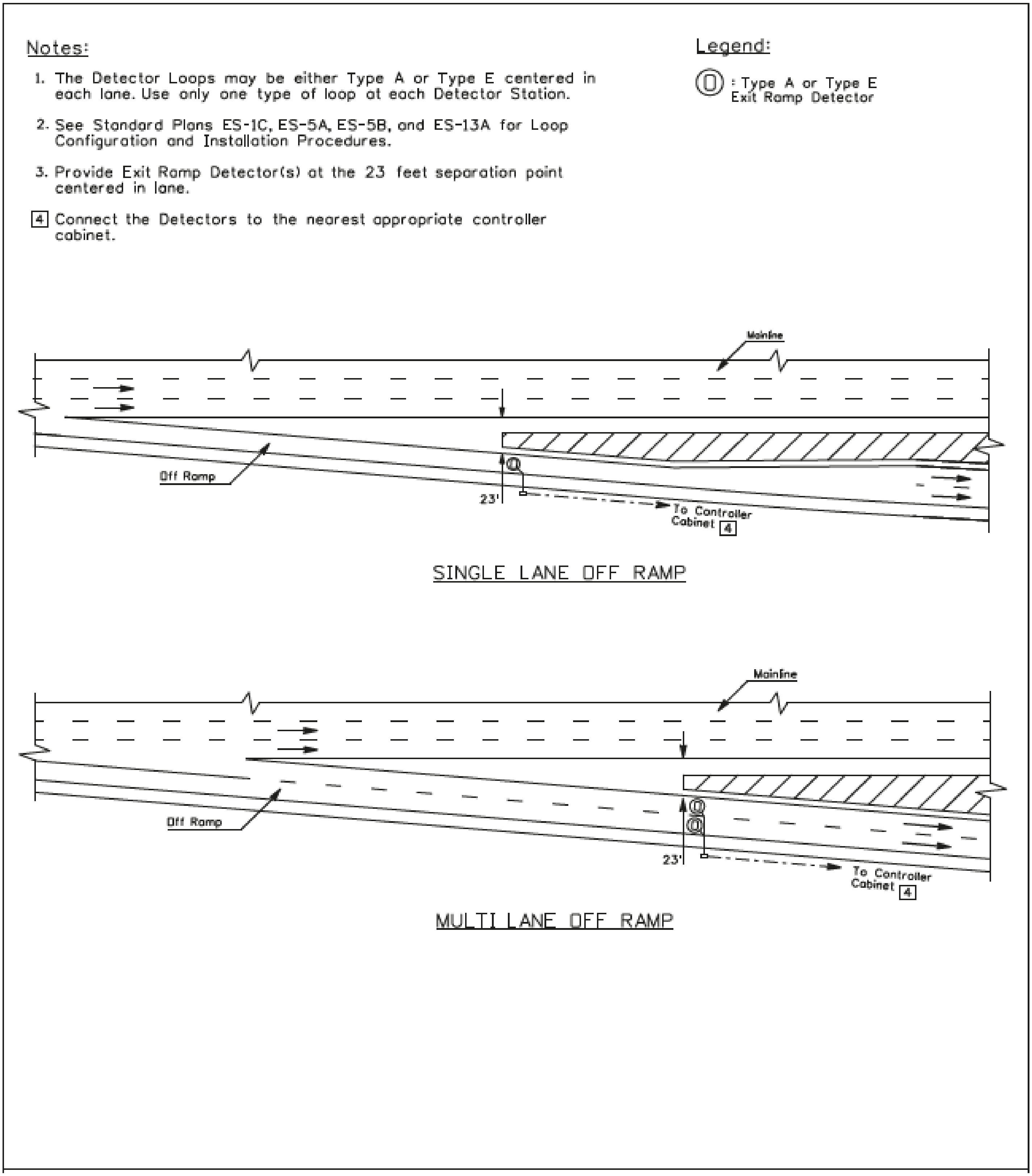


Figure 2-11. Typical Detector Layout for a Metered Connector

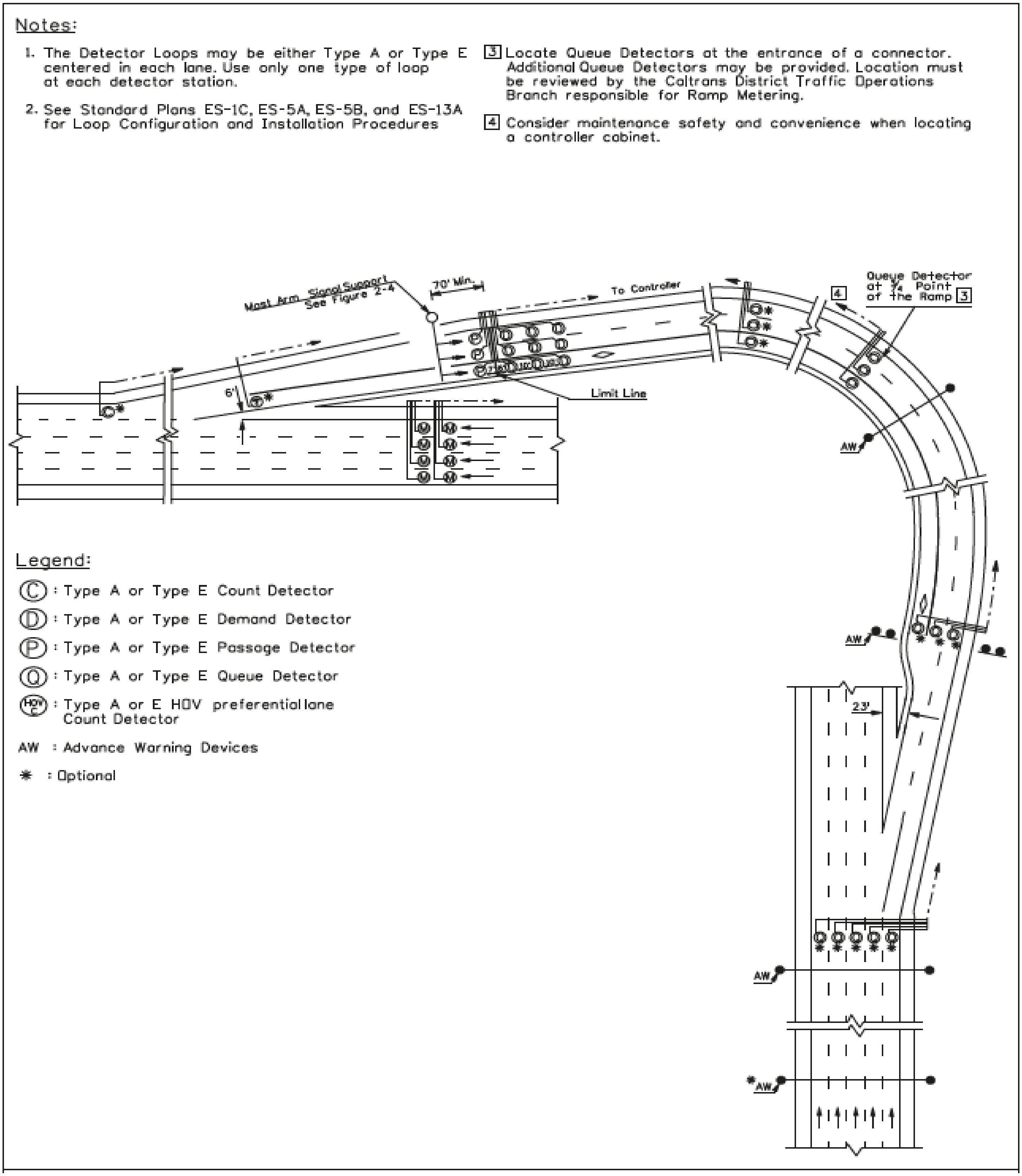


Figure 2-12. Typical Advance Warning Devices

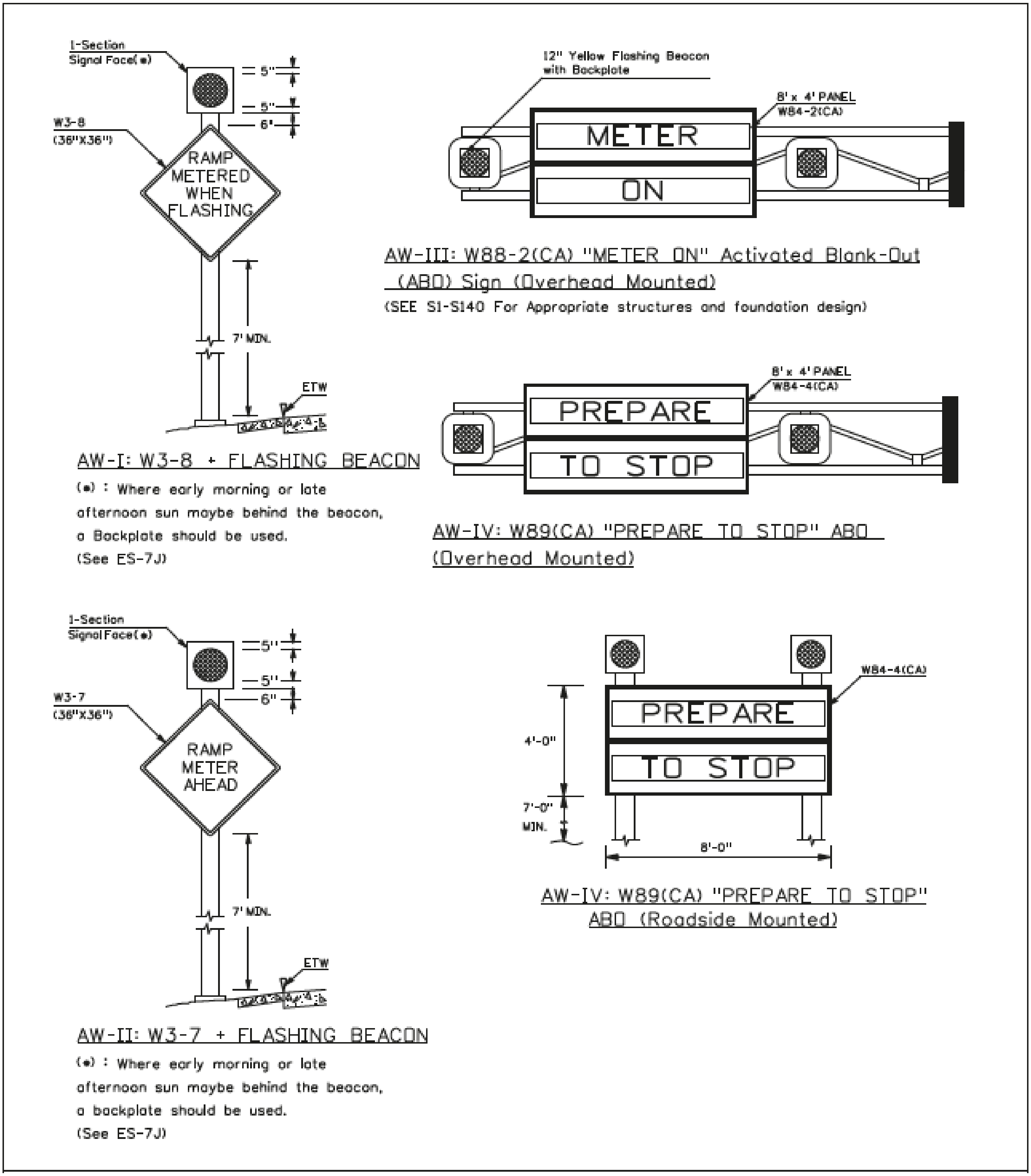
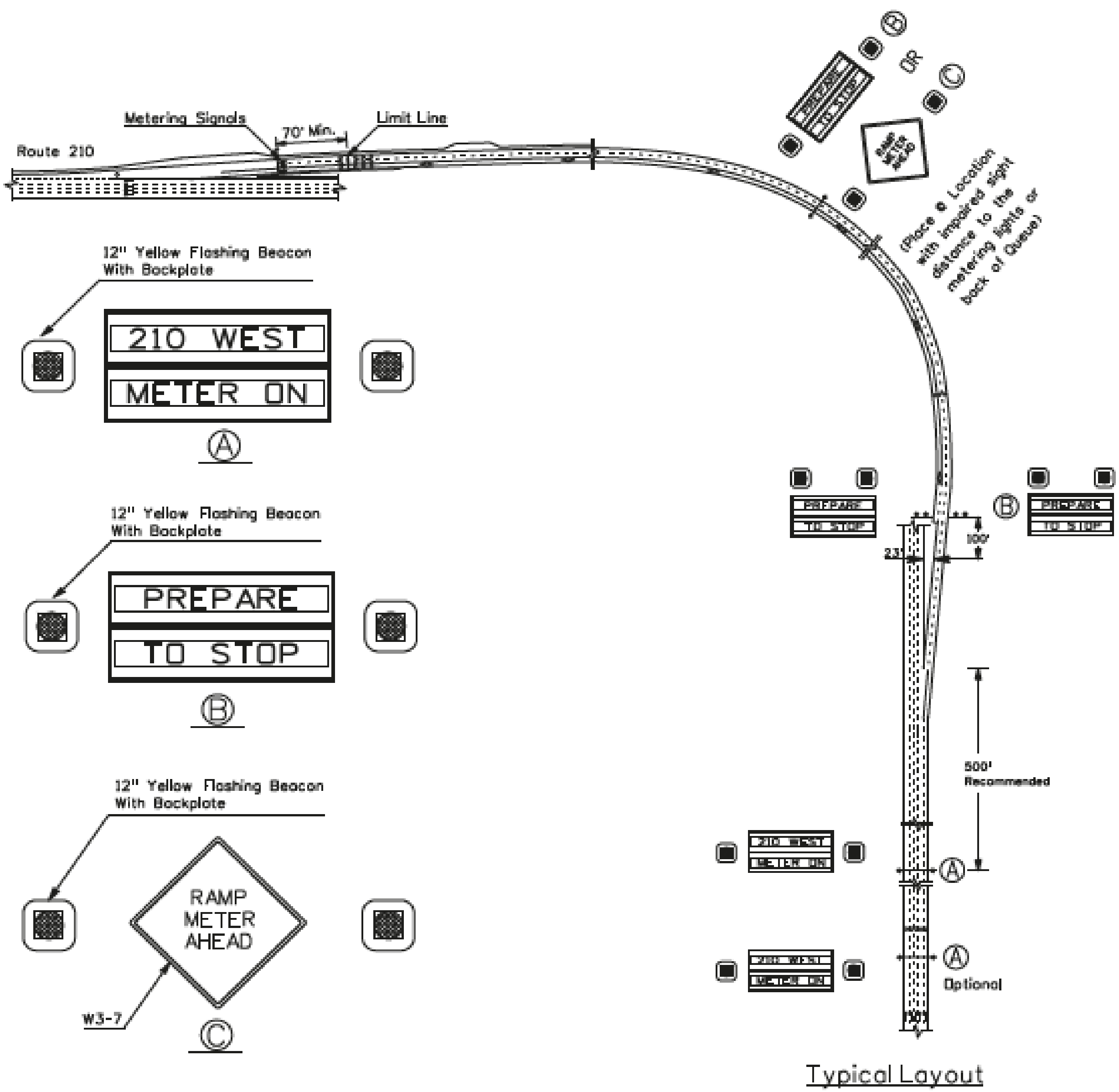


Figure 2-13. Typical Advance Warning Device Layout for a Metered Connector

Notes:

1. The minimum distance between the "PREPARE TO STOP" activated Blank-Out (ABO) 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 Introduction

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

The sign and pavement marking designations and descriptions in this *RMDM* are the same as those used in the *CA MUTCD*.

Signs shall not block the visibility to the metering signals and/or the end of queued vehicles along the entrance ramp.

The design of signing and pavement markings at metered ramps should accommodate pedestrians, bicycle traffic, and all transit users in compliance with Deputy Directive-64-R1 titled "Complete Streets-Integrating the Transportation System."

Warning and regulatory signs shall meet the standards set forth in *CA MUTCD* Section 2A.18, "Mounting Height," *CA MUTCD* Section 2A.19, "Lateral Offset," and HDM Topic 309, "Clearance." Sign supports that are not breakaway should be protected. The distances contained in *CA MUTCD* Table 2C-4, "Guidelines for Advanced Placement of Warning Signs" are for guidance purposes.

Procedural Requirement 3-1. Signing and Pavement Markings

The type, number, size, and location of signs and pavement markings specified in this RMDM require the review and concurrence by Caltrans district traffic operations branch responsible for ramp metering. Any deviation and justification shall be documented in the project file.

See Figures 3-2 to 3-7 for the typical layout of signs used at various types of metered ramps. See Figures 3-4 to 3-7 for the typical layout of pavement markings at various types of metered ramps.

3.2 Signing

3.2.1 Vehicle(s) per Green Signs, R89(CA) and R89-2(CA)

As shown in Table 3-1, the R89(CA) and R89-2(CA) regulatory signs are used to indicate the maximum number of vehicles allowed to proceed for each metering cycle. Throughout this manual, these signs will collectively be referred to as the R89(CA) series of signs.

When a Type 1 signal standard is used, attach one R89(CA) series of sign per Type 1 signal standard, 3 inches below the lower signal head, or between the upper and lower signal heads (see Figure 2-3). If visibility to the sign is obstructed, the sign may be attached to a separate signpost. When a mast-arm standard is used, provide one R89(CA), or R89-2(CA) sign 3.5 feet (center-to-center) to the right of each signal head.

The font height for signs on the Type 1 signal standard should be at least 3 inches. A font height of at least 4 inches should be used on mast-arm signs since the sign is more than 70 feet away from the stopped vehicles. For a single-lane entrance ramp, use an R89(CA) sign. For a multi-lane metered entrance ramp, use an R89-2(CA) sign for staggered release operations.

Table 3-1. Regulatory Signs

Sign Designation	Sign Image	Overall Panel Size (s)	Font and Series
R10-6 (R)		24" x 36"	5" Series D
R10-20aP or R10-20aP Alternate	 	24" x 24" or 24" x 18"	4" Series C
R13A (CA)		24" x 36"	5" Series C
R33 (CA)		24" x 36"	3" Series C
R33A (CA)		30" x 48"	4" Series D
R89 (CA)		48" x 12" 36" x 9"	4" Series C 3" Series C
R89-2 (CA)		48" x 20" 36" x 16"	4" Series C 3" Series C

The R89(CA) and R89-2(CA) sign legends must match the metering operational scheme. For example, if the metering operational scheme allows two cars to proceed than the R89(CA) and R89-2(CA) sign would read "2 CARS PER GREEN." Use the same R89(CA) series of sign legends on the Type 1 signal standard at the limit line and the mast-arm signal standard if there is one. For example, if R89-2(CA) signs are used at the Type 1 signal standards at the limit line (3-inch letters), use R89-2(CA) signs on the mast-arm standard (4-inch letters).

3.2.2 STOP HERE ON RED R10-6 (L or R) Signs

When a Type 1 standard is used, install an R10-6 sign (as shown in Table 3-1) at the right end of the limit line of metered single lanes and at both ends of the limit line of metered multi-lanes to indicate to motorists where to stop at the limit line. The arrows on these signs point toward the limit line.

When a mast-arm standard is used for a single-lane or multi-lane entrance ramp, install R10-6 signs at the limit line. The R10-6 sign should be attached to the Type 1 metering signal standard below the lower signal head, or when there is no signal standard, to a separate breakaway signpost. If the view to the sign is obstructed by a guardrail or barrier, attach the R10-6 sign to breakaway signposts that are not in the roadway, less than 3 feet from the Type 1 signal standard.

See Figures 2-3 and 3-1 to 3-5 for examples of the R10-6 (L or R) sign locations at various types of metered ramps or connectors.

3.2.3 HOV Preferential Lane Signs, R88(CA), R90-1(CA), R91-1(CA) and R94(CA)

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 requirement, and/or 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.

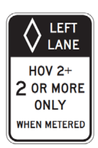
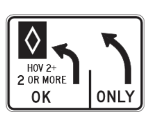
Use the R91-1(CA) sign to designate the HOV preferential lanes at metered entrance ramps or freeway-to-freeway connectors. A minimum of two R91-1(CA) signs should be placed adjacent to HOV diamond symbol pavement markings. Multiple HOV preferential lanes require the use of overhead signs. See *CA MUTCD* Section 2G.102, "Regulatory Signs for Preferential Lanes at Metered Ramps" for the R91-1(CA) sign specifications. 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."

When an HOV preferential lane is not metered, an R88(CA) (left or right lane) roadside sign is required on the same side as the HOV preferential lane and across from the metered lane limit line.

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, are metered to prevent motorist confusion.

Table 3-2 HOV Regulatory Signs

Sign Designation	Sign Image	Overall Panel Size (s)	Font and Series
R33B (CA)		24" x 60"	3" Series C & D
R33C (CA)		24" x 60"	3" Series C & D
R88 (CA) (L)		30" x 30"	5" Series C
R90-1 (CA)		24" x 30"	4" Series C & D
R91-1 (CA)		30" x 54"	4" Series C
R94 (CA)		60" x 42"	5" Series D

3.2.4 Turning Movement Restriction and Lane Control Signs for At-Grade Intersections of Local Streets with Metered Entrance Ramps, (R13A(CA), R13B(CA), R33(CA), R33A(CA), R33B(CA), R33C(CA), and R94(CA)

Turn movement restriction signs should be placed where they will be most easily seen by drivers intending to turn. Turn restrictions can be permanent, either during the at-grade intersection red phase (no right or left turn on red) or by time of day, depending on the severity of the upstream arterial back-up and times that the back-up exists.

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.

R13A(CA) or R13B(CA) static signs may be used when an engineering study finds that one or more conditions exist. Refer to *CA MUTCD* Section 2B.54, "No Turn on Red Signs" for a list of these conditions. The size of the R13A(CA) and R13B(CA) sign is dependent on the number of traffic lanes of the local street. See Table 3-1 for sign sizes. Install the signs according to *CA MUTCD* Section 2B.54, "No Turn on Red Signs." A supplemental sign plaque R10-20aP with applicable hours may be mounted below the R13A or R13B signs to indicate the hours of restriction during certain times. The R13A(CA), R13B(CA), R33(CA), and R33A(CA) signs are shown in Table 3-1.

R33(CA) and R33A(CA) static signs may be used if left turns are prohibited during certain time periods. Refer to *CA MUTCD* Section 2B.18 for the location of the R33(CA) and R33A(CA) signs.

Procedural Requirement 3-2. Turning Movement Restriction and Lane Control Signs for At-Grade Intersections of Local Streets with Metered Entrance Ramps

Obtain the concurrence of local agencies and Caltrans district traffic operations branch responsible for signing and pavement markings before installing signs on local roadways.

Table 3-3. Warning Signs

Sign Designation	Sign Image	Overall Panel Size (s)	Font and Series
W3-7		36" x 36" single post 72" x 72" Oversized for overhead mounting	5" D Series 10" D Series Oversized for overhead mounting
W3-8		36" x 36"	4" D Series
W4-2L		36" x 36"	
W4-2R		36" x 36"	
W9-1 (R)		36" x 36"	6" D Series

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 signpost is required to indicate when the ramp metering is active. See Section 2.6.1, "Advance Warning Devices" for details regarding these signs.

3.2.6 Lane Ends Warning Signs

Install W4-2 (L or R) ground-mounted advance-warning signs to inform motorists of a reduction in the number of traffic lanes for metered multilane freeway entrance ramps or connectors. Use the W4-2 (L or R) sign that matches the direction of the lane-drop.

Install the W4-2 (L or R) signs at the beginning of the lane-drop taper.

An additional W9-1 (L or R) sign may also be installed upstream of the limit line as additional advance warning to emphasize the traffic lane is ending and a merging maneuver is downstream. Use the W9-1 (L or R) sign that matches the direction of the lane-drop.

3.2.7 Activated Blank-Out Signs

Three activated blank-out signs are used for metered freeway connectors' 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 freeway connector meters are in operation. See Section 2.6.2, "Advance Warning Devices" for details regarding these signs.

Table 3-4. Activated Blank-Out Signs

Sign Designation	Sign Image	Overall Panel Size (s)	Font and Series
W88-2 (CA)	METER ON	96" x 48" (10")	96" x 48" (10")
W88-3 (CA)	210 WEST METER ON	96" x 48" (10")	96" x 48" (10")
W89 (CA)	PREPARE TO STOP	96" x 48" (10")	96" x 48" (10")

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. Retroreflective 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 3-9 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 CA MUTCD, Section 3B.20 "Pavement Word, Symbol, and Arrow Markings."

3.3.3 Limit Line

Meter limit lines shall be 18 inches wide placed transversely from edge of traveled way (ETW) to ETW across all metered entrance ramp lanes, including metered HOV preferential lanes. Staggered limit lines shall not be used. Refer to Section 1.7, "Limit Line Location" for location requirements and Section 2.2.3, "Limit Line Lighting" for limit line lighting requirements.

3.3.4 Diamond Shaped Pavement Markings Used to Identify HOV Preferential Lane Symbols

The HOV preferential lane shall be marked with the standard HOV elongated diamond symbols spaced at a maximum of 180 feet apart. The center of the HOV symbol should coincide with the center line of each HOV preferential lane. Begin the sequence of HOV symbols at the entrance to the HOV preferential lane. A minimum of two HOV symbols should be installed at each metered freeway entrance ramp or connector. One HOV symbol must be placed within 30 feet upstream of the limit line. The maximum of 180-foot spacing requirement should be maintained by adjusting the spacing between the HOV symbol nearest to the limit line and the prior HOV symbol immediately upstream. For details, please refer to Figure 3-6.

The pavement word marking "HOV LANE" may be installed 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 line pavement markings are used to separate the travel lanes from an adjacent shoulder. For the left edge line and pavement markers at a metered entrance ramp, use the following: (1) the *CA MUTCD* Detail 25A shown in the *CA MUTCD* Figure 3A-105(CA) between the entrance to the ramp and the gore area, (2) Detail 36A shown in *CA MUTCD Figure* 3A-110(CA) for merging after the 6 -foot separation point, or (3) Detail 36B for merging onto an auxiliary lane shown in *CA MUTCD* Figure 3A-110(CA). For the right edge line, use Detail 27B shown in *CA MUTCD* Figure 3A-106(CA).

Lane line pavement markings delineate the separation of traffic lanes that have the same direction of travel. Separate the HOV preferential lane and the GP lane(s) with Detail 43 shown in *CA MUTCD* Figure 3A-113(CA). As shown in Figure 3-6, to distinguish the HOV preferential lane line (Detail 43) from the GP lane line at the access opening, use Detail 40 shown in *CA MUTCD* Figure 3A-113(CA).

For the lane line pavement markings between the GP lanes, use 6-inch-wide Detail 8 or 9A shown in *CA MUTCD* Figure 3A-102(CA) when the approaching speed is 40 mph or less, and use Detail 11 or 12A when the approaching speed is higher than 45 mph shown in *CA MUTCD* Figure 3A-102(CA). To discourage last-minute lane changes, use a 6-inch-wide lane line in place of the Detail 8, 9A,11, or 12A 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 in the Multi-Lane 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-drop transition zone starts on the right side of the entrance ramp so traffic merges to the left, until only the leftmost lane remains. As shown in Figure 3-7, the lane-drop transition zone starts at the limit line or some distance downstream of the limit line and ends at the 6-foot separation point or the convergence point when an auxiliary lane is present. 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 upstream segment.

3.3.6.1 Two-Lane Metered Entrance Ramps and Connectors

For a two-lane metered freeway entrance ramp and connector, the lane-line separating the two lanes ends at the beginning of the lane-drop transition zone. According to the taper ratio, the right ETW should taper to the 6-foot separation point or the convergence point when an auxiliary lane is present.

3.3.6.2 Three-Lane Metered Entrance Ramps

HOV preferential lane on the left side: For a three-lane metered entrance ramp with one HOV preferential lane on the left side, as shown in Figure 3-7, extend the lane line (Detail 43) between the HOV preferential lane and GP lanes 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. Separate the remaining two GP lanes from the limit line to the beginning of the lane-drop transition zone with the Detail 8, 9A, 11, or 12A lane-line shown in *CA MUTCD* Figure 3A-102(CA). The type of detail used is dependent on the design speed.

HOV preferential lane on the right side: For a three-lane metered entrance ramp, as shown in Figure 3-8, the lane line (Detail 8, 9A, 11, or 12A) between the two left GP lanes extends downstream until the lateral distance between the left and right ETW is two lane widths. The lane line between the HOV preferential lane (Detail 43) and GP lane ends at the starting point of the lane-drop transition zone, regardless of the total number of lanes.

Without HOV preferential lane: For a three-lane metered 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 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.

3.3.6.3 Three-Lane Metered Connector

HOV preferential lane on the left side: For a three-lane metered connector with an HOV preferential lane on the left, as shown in Figure 3-7, extend the lane line (Detail 43) between the HOV preferential lane and GP lane 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 downstream for the 300 feet of constant cross-section using *CA MUTCD* Detail 8, 9A, 11, or 12A. The lane line between the GP lanes terminates at the beginning of the final lane drop transition zone.

HOV preferential lane on the right side: When an HOV preferential lane is on the right side of the metered freeway connector, drop the HOV preferential lane line (Detail 43) before any GP lane lines so traffic merges to the left. The lane line (Detail 43) 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 freeway connector, as shown in Figure 3-8, the lane line (Detail 8, 9A,11, or 12A) between the two left GP lanes extends downstream until the lateral distance between the left and right ETW is two lane widths.

Without HOV preferential lane: 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. This lane line (Detail 8, 9A, 11, or 12A) continues until the lateral distance between the left and right ETW is two lane widths. The lane line (Detail 8, 9A, 11, or 12A) between the two right GP lanes terminates at the beginning of the final lane-drop transition zone. See Figure 3-9 for pavement marking details and dimensions.

Figure 3-1. Typical Signing and Pavement Marking (2-Lane Entrance Ramp, 1 GP Lane + 1 HOV Preferential Lane)

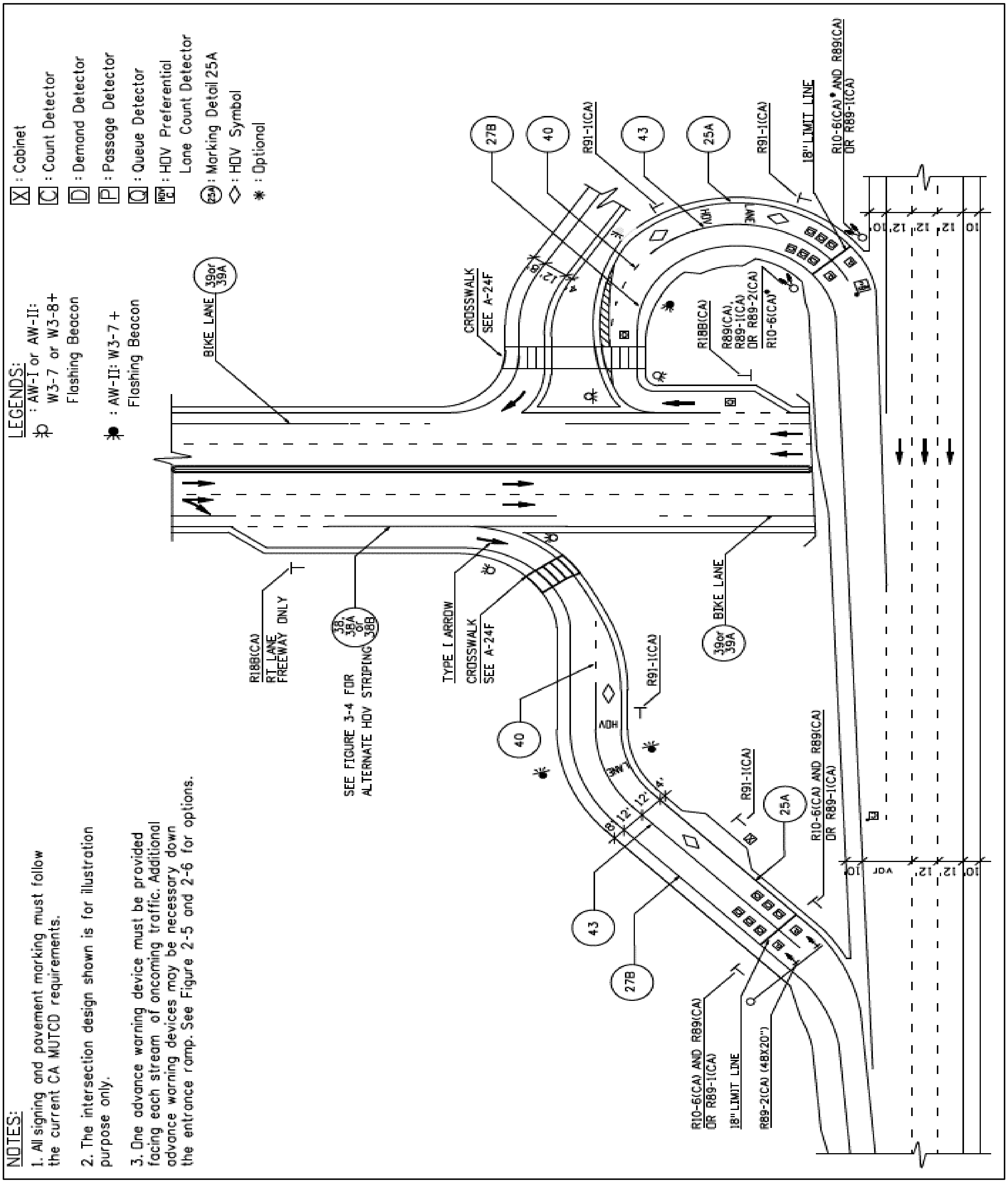


Figure 3-2. Typical Signing and Pavement Marking (2-Lane Entrance Ramp with Intersection/HOV Preferential Lane)

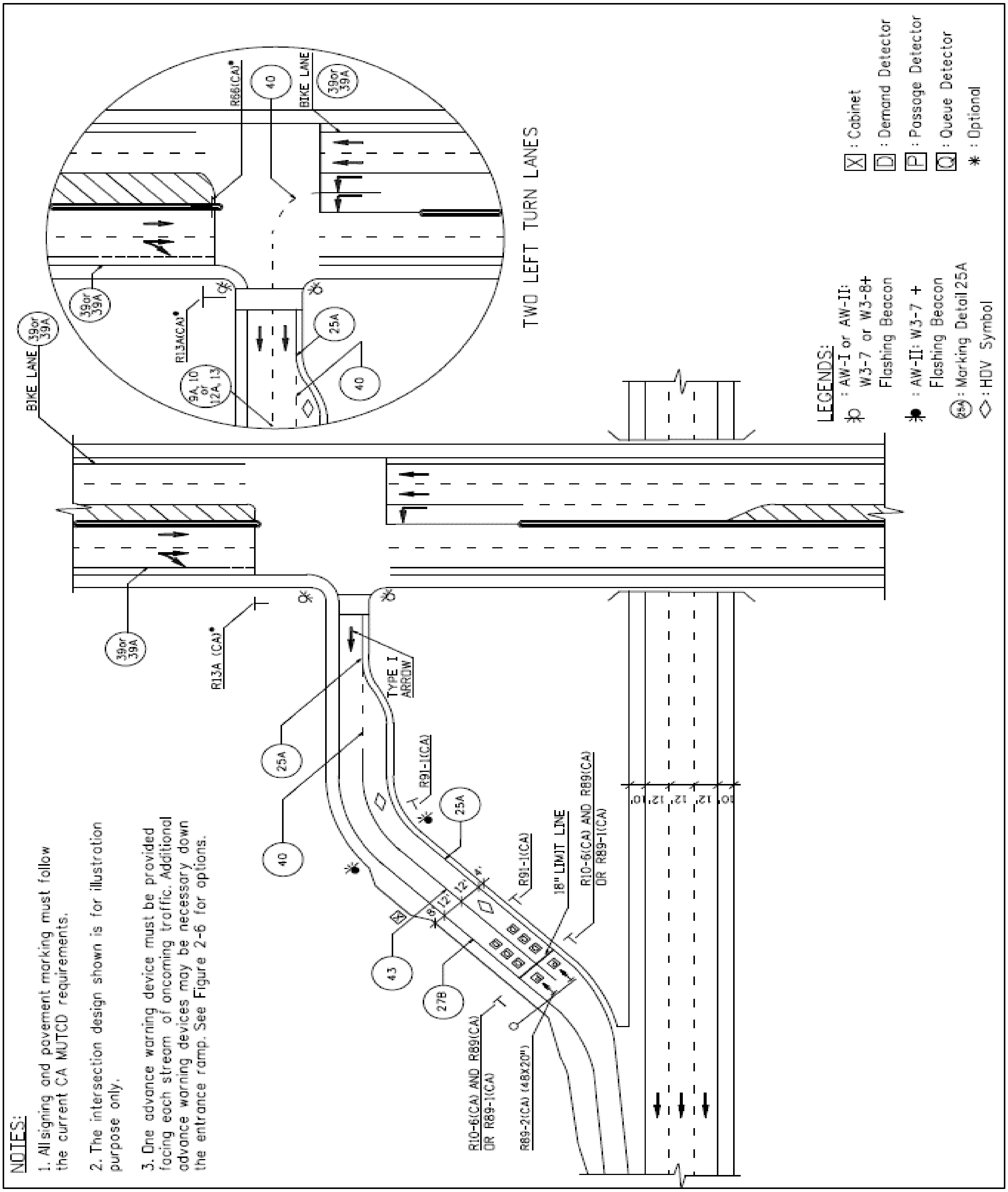


Figure 3-3. Typical Signing and Pavement Marking (3-Lane Entrance Ramp, 2 GP Lanes + 1 HOV Preferential Lane)

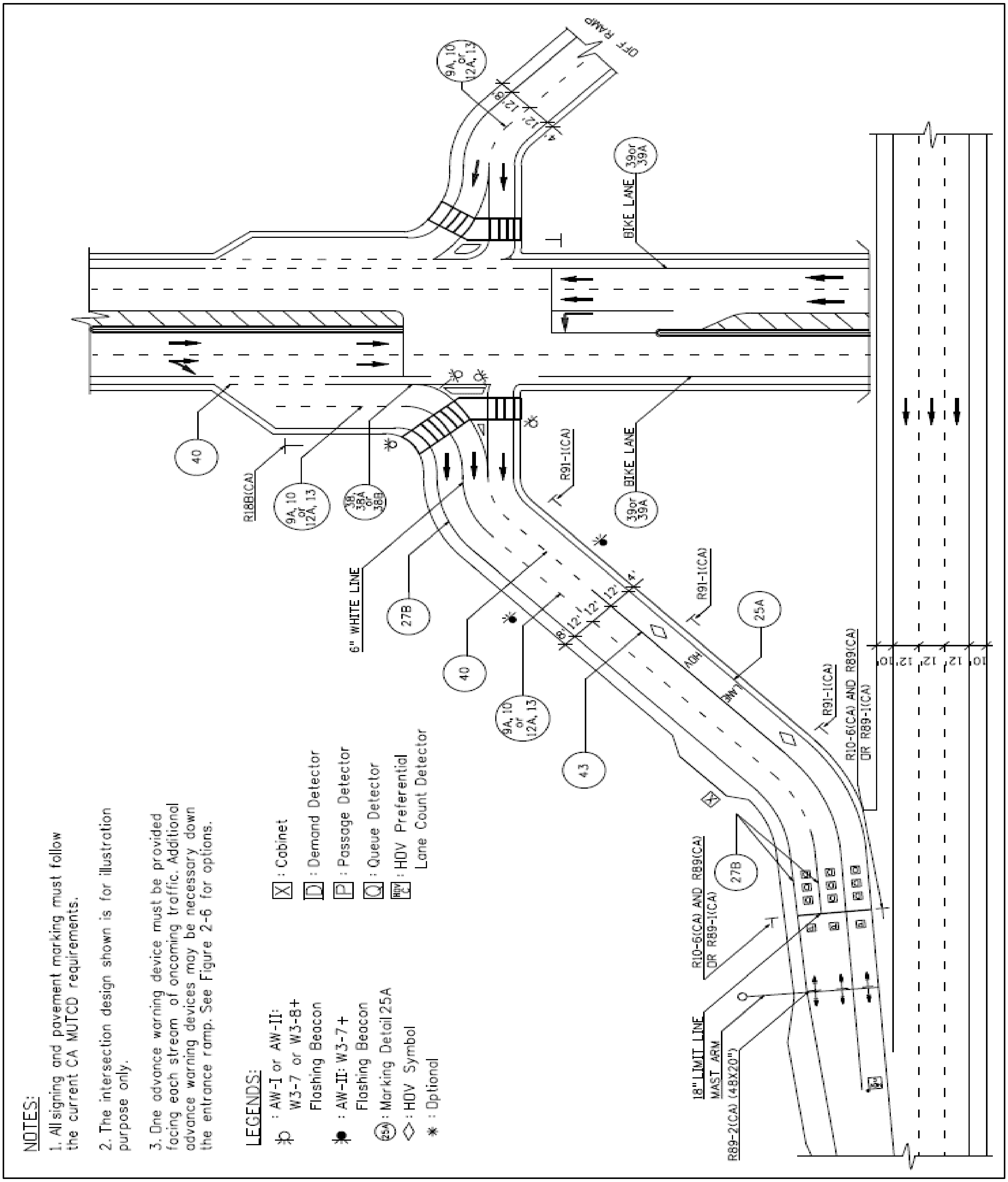


Figure 3-4. Typical Signing and Pavement Marking (3-Lane Loop Entrance Ramp, 2 GP Lanes + 1 HOV Preferential Lane)

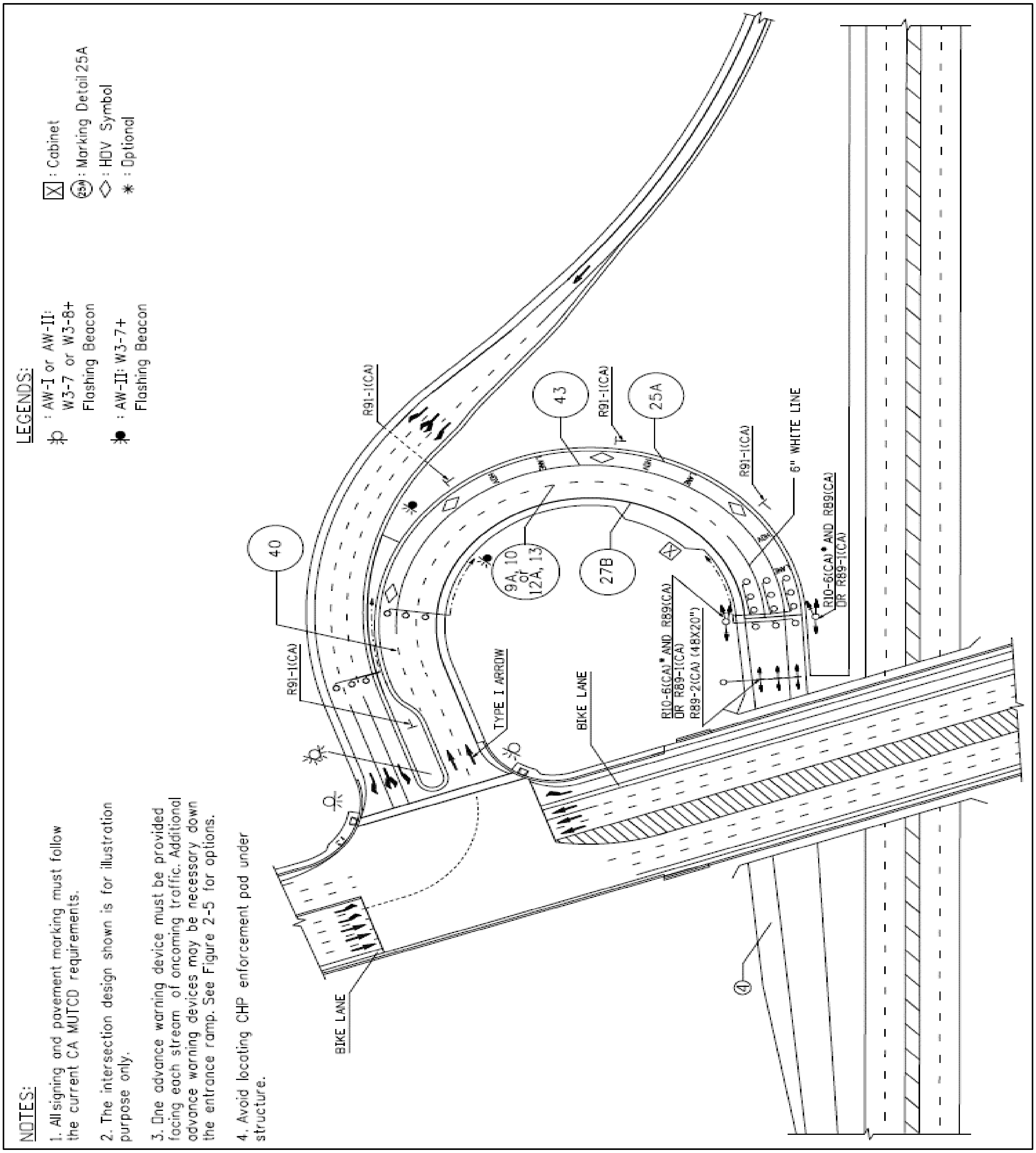


Figure 3-5. Typical Signing and Pavement Marking (3-Lane Loop Entrance Ramp, 2 GP Lanes + 1 HOV Preferential Lane)

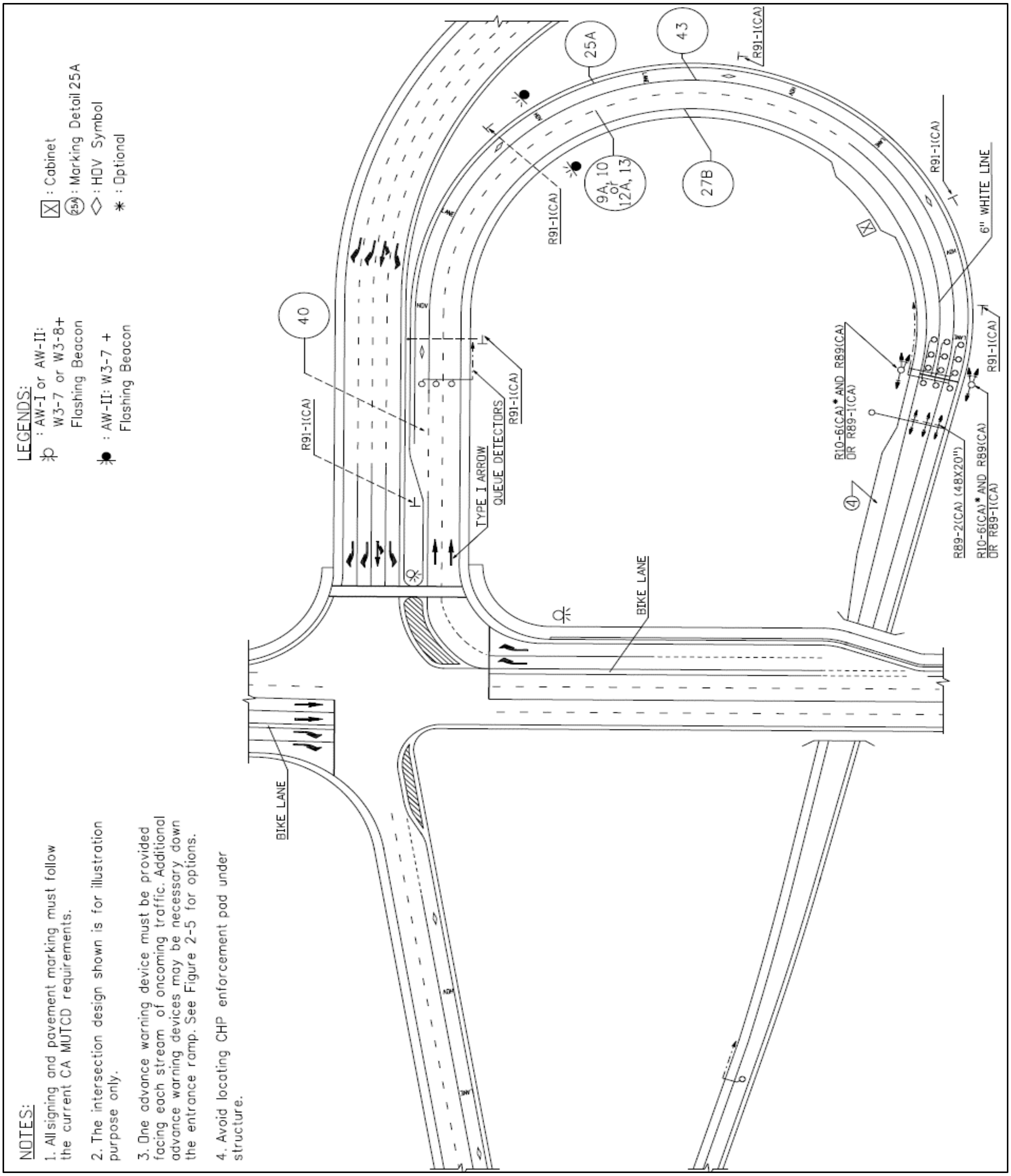


Figure 3-6. Typical HOV Preferential Lane Pavement Markings

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. For situations with fewer or more general purpose lanes, just reduce or add lane lines (Detail 9, 10 or 12, 13).

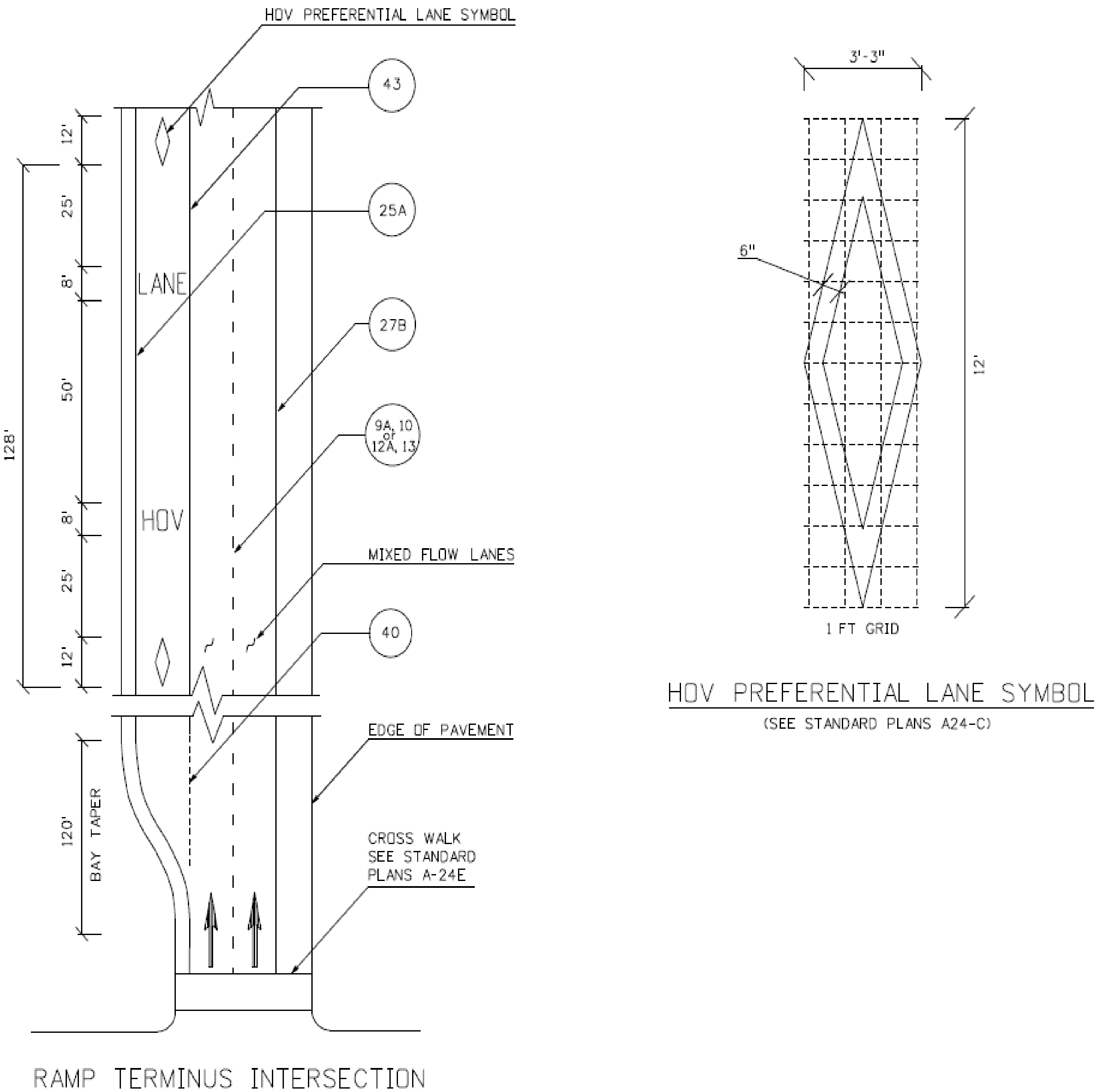


Figure 3-7. Lane-Drop Transition Zone Pavement Markings (2 GP Lanes + 1 HOV Preferential Lane on the Left Side)

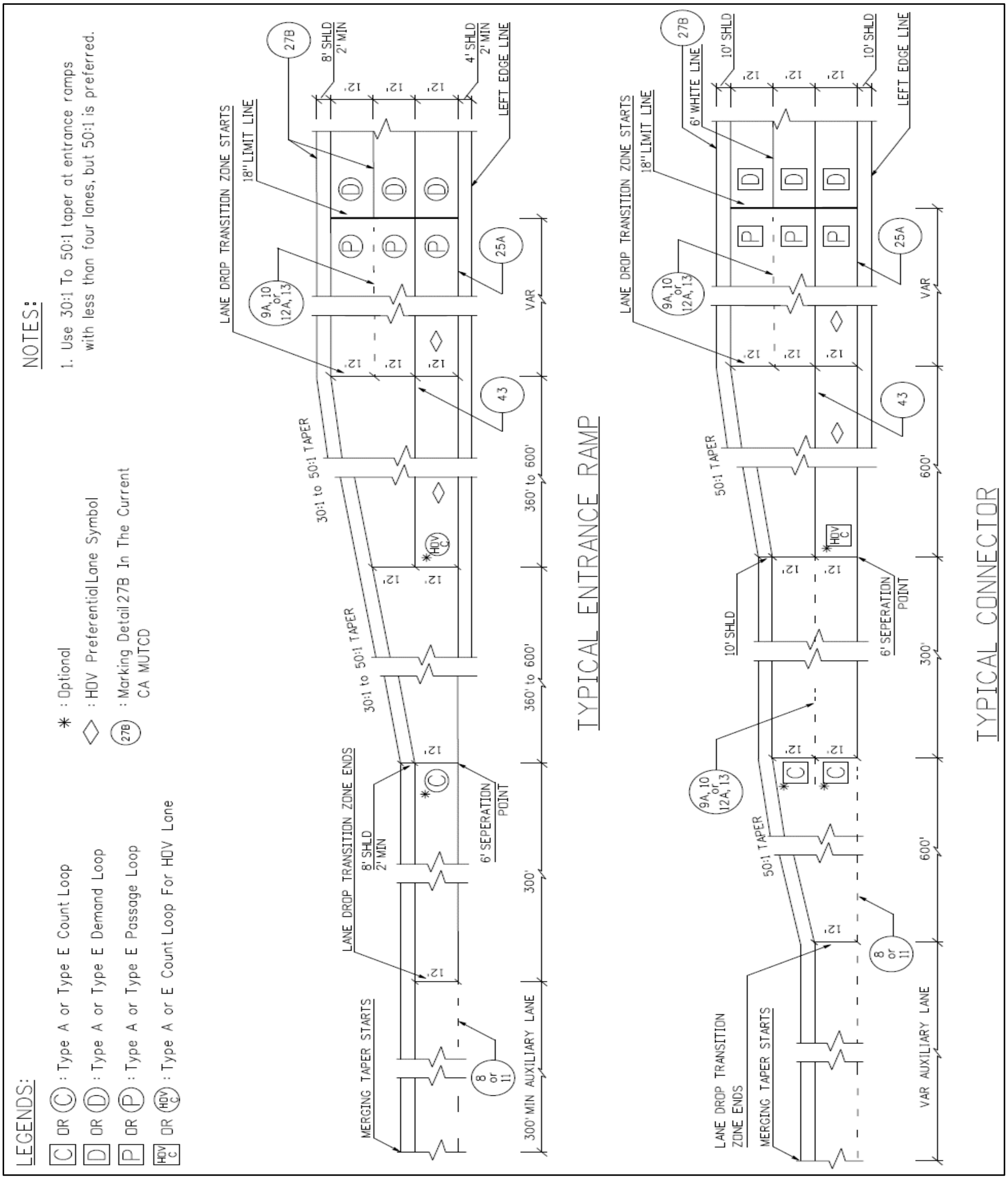


Figure 3-8. Lane-Drop Transition Zone Pavement Markings (2 GP Lanes + 1 HOV Preferential Lane on the Right Side)

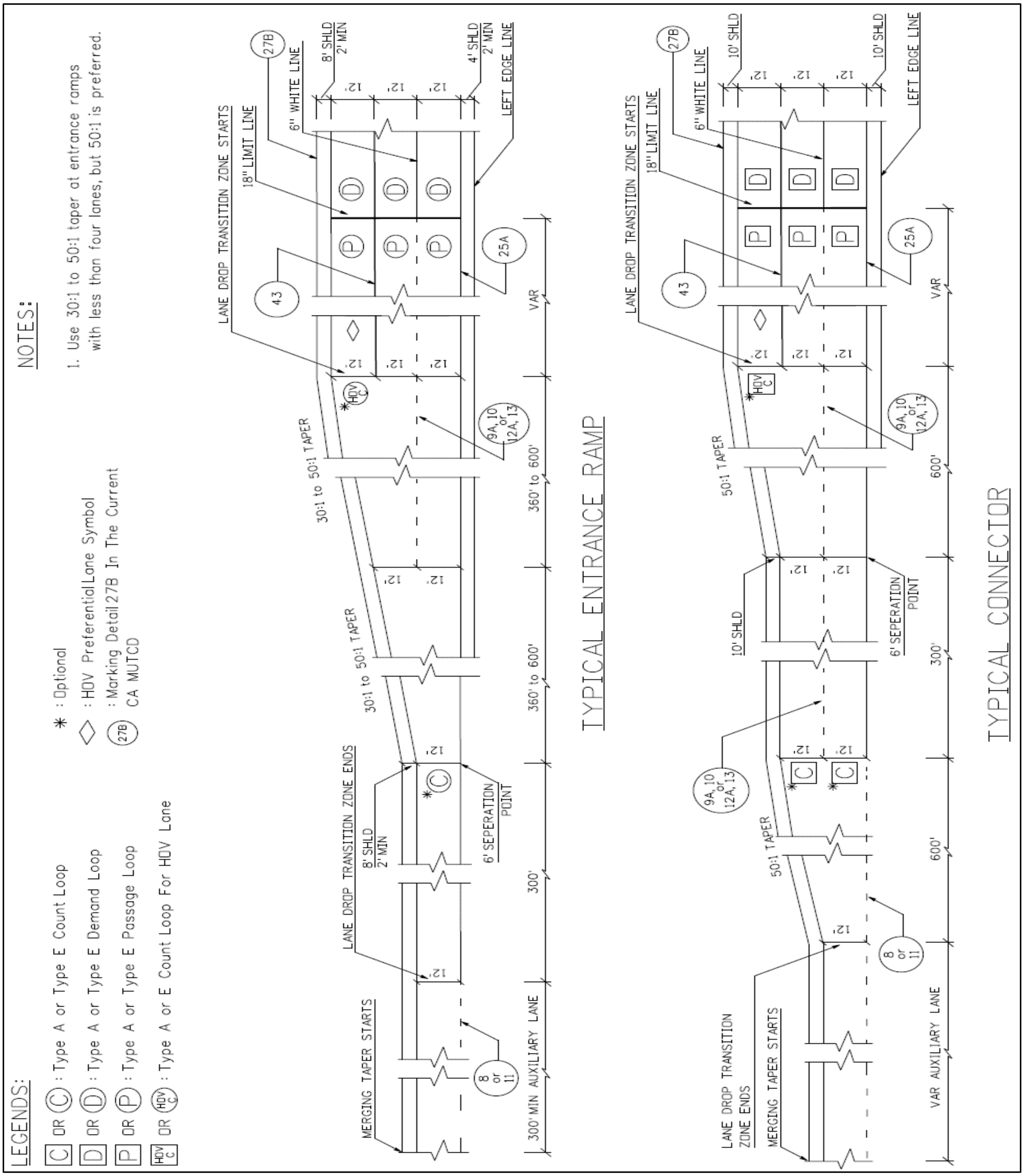
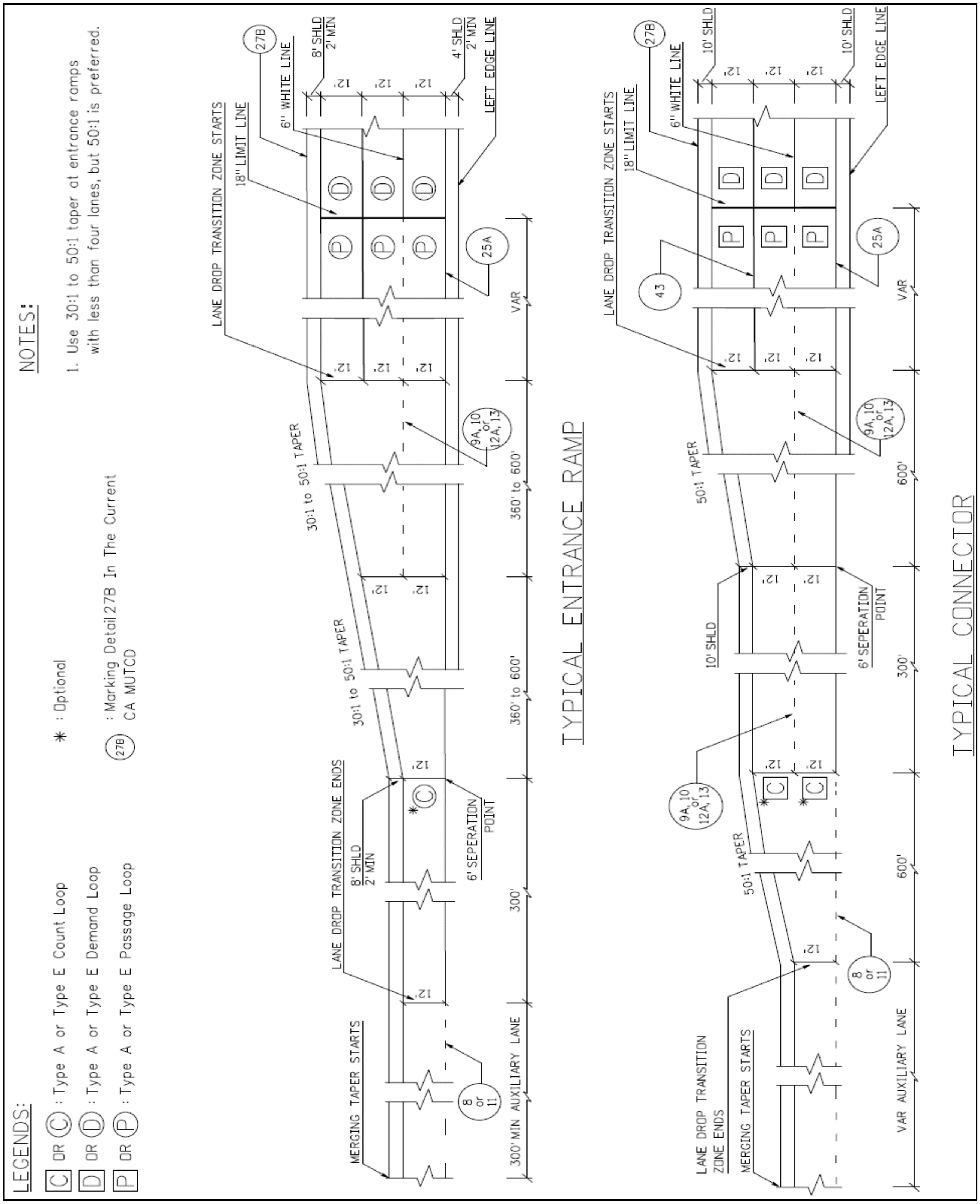


Figure 3-9. Lane-Drop Transition Zone Pavement Markings (3 GP Lanes + No HOV Preferential Lane)



Appendices

Appendix A: Deputy Directive 35-R1

Appendix B: Sample – Exception(s) To Ramp Metering Policy Fact Sheet

Appendix C: Design Checklist

Appendix D: Instructions for Using Arrival-Discharge Bar Chart at Existing Metered Ramps and Connectors

Appendix E. Acronyms

Appendix F. Glossary

Appendix G. Bibliography

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

<u>Chief, Division of Traffic Operations:</u>

- 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.

<u>District Construction Engineers (Electrical and Civil), Resident Engineers, and Encroachment Permit Inspectors</u>:

- 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

1/6/2011
Date Signed

Appendix B: Sample – Exception(s) To Ramp Metering Policy Fact Sheet

Dist - Co - Rte - PM

Program Code

Project Number

Project Name

EXCEPTION TO RAMP METERING POLICY FACT SHEET

Type of Project and Location

Prepared by:

Registered Engineer (NAME)	*DATE*

Approval recommended by:

DISTRICT RAMP METERING BRANCH CHIEF	*DATE*

Approval By:

DEPUTY DISTRICT DIRECTOR, TRAFFIC OPERATIONS	*DATE*

Concurrence by:

HQ TRAFFIC OPERATIONS *CHIEF, OFFICE OF MOBILITY PROGRAMS*	*DATE*

1. PROJECT DESCRIPTION Briefly describe the project. Note the type of project, funding source, schedule, and/or major elements of work. Identify funding and scheduling constraints.
2. RAMP METERING POLICY NON-COMPLIANCE FEATURES Describe the proposed or existing ramp metering policy non-compliance feature(s).
3. GENERAL JUSTIFICATION Explain why the proposed ramp metering policy exceptions will not degrade safety or increase the traffic delay currently experienced.
4. REASON FOR THE EXCEPTION Be thorough but brief. Supportive factors may include right-of-way or space constraints, environmental concerns, inordinate costs, etc. Provide an estimate of the added cost above the proposed project cost required to conform to the ramp metering policy. The estimate does not have to be highly developed but must be realistic.
5. 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.
6. REMARKS Note clarifying remarks. Discuss impacts on project delivery schedule and project costs, if any. Discuss the impacts of features that are not in compliance with the ramp metering policy.
7. ATTACHMENTS Provide: • Location(s) map and/or vicinity map for the project, indicating the location of the requested exception(s) to the ramp metering policy. • Cross sections, layout drawing(s) and/or special details to illustrate the policy non-compliance condition. • Traffic volumes at the location(s) of the requested Policy Exception Fact Sheet. • Summary of estimated cost of compliance. • Letters, resolutions, and traffic studies, which help to clarify the reasons for the exception request. • If applicable (for an HOV preferential lane policy exception), provide a map of park and ride lot locations, regular and express bus routes, and metered ramp locations and locations of proposed or existing HOV lanes.

Appendix C: Design Checklist

GEOMETRIC DESIGN

Number of lanes:

- Provide one metered lane per 900 VPH demand. Calculate GP and 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.
- Provide HOV preferential lane(s) at all metered ramp/connector locations per latest version of Deputy Directive (DD-35).Provide an approved Exception to HOV lane Policy Fact Sheet for metered freeway entrance ramps and connectors without HOV preferential lanes.

1. Lane and Shoulder Widths:
   - Provide 12-foot lanes, plus truck off-tracking on ramps having a curve radius less than 300 feet, according to HDM 504.3 "Ramps" (1) "General" (b) "Lane Width."
   - Provide ramp shoulder widths according to HDM Table 302.1 "Standards for Paved Shoulder Width."
2. Pavement Structural Section:
   - Provide full pavement structural section for the shoulders.
   - Consider using a PCC pavement pad to increase detector loop longevity in areas prone to flexible pavement deterioration. For example, next to the limit line.
3. Queue Storage:
   - Provide storage for 7% of the peak hour design volume (consider GP and HOV demand separately).
   - Use 29 feet per vehicle for storage length calculations.
4. Acceleration Design:
   - Locate the limit line, so vehicles stopped at the limit line can reach the merging speed specified by AASHTO.
5. Taper Design:
   - Provide a minimum 50:1 for merging from the metered freeway entrance ramp onto the freeway.
   - For multilane metered entrance ramps, provide a 30:1 to 50:1 lane-drop taper ratio.

- For multilane metered connectors, provide a lane-drop transition length equal to WV. All lane drop transitions on metered multilane connectors shall be accomplished with a minimum taper ration of 50:1 minimum taper ratio.

6. Auxiliary Lane:
   - Provide a minimum length of 300 feet of auxiliary lane downstream of the convergence point for single and multilane ramps.
   - Install a minimum length of 1000 feet of auxiliary lane, when truck percentages and ascending grades warrant.
   - Install a minimum length of 1000 feet of auxiliary lane minimum when design traffic volume > 1500 VPH.
7. CHP Enforcement Area:
   - Provide an enforcement area downstream of the limit line.
8. Maintenance Vehicle Pullout:
   - Provide an MVP adjacent to the controller cabinet.
   - Provide a paved walkway between the MVP and metering controller cabinet.
9. Entrance Ramp Terminal Design at the At-Grade Intersection:
   - Eliminate free-flow access at the at-grade intersection of the metered entrance ramp.
   - Consider pedestrian/bicycle traffic at the at-grade intersection, bulb-out the HOV lane access at the ramp entrance.
   - Provide access to the metered ramp HOV preferential lane near the ramps entrance with a bulb-out design.

ELECTRICAL DESIGN

10. Signal Head Placement:
    - 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 visible from the CHP enforcement area.
    - Horizontally align mast-arm overhead signal heads with center of the controlled lanes (in other words, at the center of lanes as viewed from the limit line).
    - Install Type 1 standards at loop ramps outside of the mainline CRZ, or shield with guardrail or barrier.
11. Placement of Cabinets, Conduits, and Signal Standards:
    - Install cabinets outside the required CRZ or shield them from erratic vehicles.
    - Place Type 1 standards at least 1 foot downstream of the trailing edge of the limit line and 3 feet offset from the outside edge of the shoulder, or shield with guardrail or barrier.
    - Consider trade-offs between overhead and roadside signal supports.

- Obtain approval when non-standard supporting structures are used.

12. Placement of Detectors:
    - Provide the type, location, and size specified in this RMDM (mainline, demand, passage, queue, HOV preferential lane count, and exit ramp).
    - Equip an HOV preferential lane the same way as any other metered lanes.
    - Equip metered connectors the same way as metered entrance ramps.
13. Check Other Electrical Design Details:
    - Select the type and location of telephone and controller cabinet.
    - Select the type, location and size of electrical wires and conduits.
    - Select and design communication system for metering (fiber, wireless, or wired).
    - Include provisions and costs for power and communications equipment in the PS&E package.
    - Include integration of the metering system with the central transportation management system in specifications and estimates.

SIGNING AND PAVEMENT MARKING DESIGN

14. Placement of Metering Limit Line:
    - Balance the need for metered vehicle storage and acceleration.
15. Regular Signing and Pavement Marking:
    - Provide the signs and pavement markings specified in this RMDM.
    - Provide a solid lane line between the HOV and GP lanes.
    - Install HOV preferential lane sign (R91-1(CA)) package based on part-time or full-time operation.
    - Provide R89(CA) sign series on the mast-arm signal standard and Type 1 signal standards.
16. Placement of advance warning signs:
    - Provide advance warning signs at the entrance to the metered freeway entrance ramp, or connector facing oncoming traffic.
    - Provide two advance warning signs on each side of multilane metered freeway entrance ramps or connectors between the entrance to the entrance ramp or connector and the limit line.
    - Provide additional advance warning signs based on ramp geometry and location of the end of queue.
    - Obtain approval when non-standard supporting structures are used.

Appendix D: Instructions for Using Arrival-Discharge Bar Chart at Existing Metered Ramps and Connectors

The arrival-discharge bar chart below is a visual representation of the arrival and discharge rates during 0.1-hour (6-minute) time intervals. The scale on the left vertical axis is vehicles/hour. The scale on the right vertical axis is (x 100 vehicles/hour). The scale on the horizontal axis is one unit = 0.1 hour. Each unit grid area under the arrival-discharge rate curves represents 100 vehicles/hour x 0.1 hour = 10 vehicles-hour/hour = 10 vehicles.

Use the bar chart as explained below to calculate the maximum queue during the delay (vehicles), total delay (vehicle hours), total number of vehicles delayed (vehicles), and average delay experienced by each vehicle (hours).

1. Plot the arrival rate curve for each 0.1-hour (6 minute) period with vertical bars. The chart can accommodate a maximum study period of 1.5 hours.
2. On the same chart, plot the discharge rate in the same manner.
3. To calculate delay, go to the point where the arrival rate matches the discharge rate (i.e., the point where vehicle delay starts). The starting point for delay is "time is 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, record the arrival rate of VPH from the left vertical axis of the arrival-discharge bar chart multiplied by the time interval over which the vehicles arrived (100 vehicles/hour x 0.1 hour). This value is the number of vehicles arriving during that 0.1 hour of time. 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 discharge rates of VPH and record it on Line B.
6. Calculate delta (Δ) for each 0.1-hour time interval. Delta (Δ) is the difference between the cumulative values of Lines A and B, taken from the point "time is zero" to the time interval in question.
7. Delta (Δ) continues to increase if the arrival rate exceeds the discharge rate. At the point where the discharge rate exceeds the arrival rate, the delta value begins to decrease representing dissipation of the queue. When delta reaches zero, there is no delay.
8. Determine the maximum delta (Δ) and sum of the deltas (Δ). Use these values to calculate the maximum queue during the delay (number of vehicles), total delay (vehicle hours), total number of vehicles delayed (number of vehicles), and average delay experienced by each vehicle (hours/vehicle). See below for summary of calculations.

Maximum number of vehicles in the queue during the delay: The number of vehicles in the queue for each 0.1 time period of the delay is the difference between the summation of the vehicles that arrive and discharge during each 0.1hour time interval. The maximum number of vehicles in the queue occurs at the end of the 0.1-hour time period when the summation of the vehicles that discharged exceeds the summation of the vehicles that arrived.

Number of vehicles in the queue during the delay (for the time period between "time is zero" and the time in question) = (Σ A - Σ B) (100 vehicles/hour) x 0.1 hour = vehicles

(e.g., maximum number of vehicles in the queue during the delay = (36.04 – 30.00) (100 vehicles/hour) x 0.1 hour = 60.4 vehicles)

Total delay (vehicle-hours): All vehicles stopped for the queue experience some delay. The total delay is the sum of the delays that occurs during each study period as long as there is a queue (i.e., from "time is zero" to the time when "delta reaches zero").

Total Delay = Σ (A_i – B_i) (Σ grid areas from where "time is zero" to the time when "delta reaches zero" x (10 vehicles/grid area) x 1/10 (hour) = vehicle hours

= $\Sigma \Delta_i$

(Example: total delay = $\Sigma \Delta$ = 26.8 grid areas (10 vehicles/grid area.) x 1/10 (hour) = 26.8 vehicle hours)

Total number of vehicles delayed (number of vehicles): To some extent every vehicle that arrives during the time when there is a queue is delayed. At the point where the discharge rate exceeds the arrival rate, delta begins to decrease, representing dissipation of the queue. When delta reaches zero there is no further delay. The total number of vehicles delayed are all the arriving vehicles or the total grid area under the arrival rate curve from "time is zero" to the time when the queue ends (delta reaches zero).

Total number of vehicles delayed = (Σ of grid areas under the arrival curve during delay) x 10 (vehicles/grid unit area)

= ΣA_i

(Total number of vehicles delayed = 48 (Σ of grid areas under the arrival curve during delay) x 10 (vehicles/grid area) = 480 vehicles

Average delay experienced by each vehicle (hours/vehicle): Delay occurs for every vehicle that arrives during the time when there is a queue.

Average delay experienced by each vehicle = total delay/total number of vehicles delayed

[average delay experienced by each vehicle = 26.8 (vehicle hours)/480 vehicles = 0.06 hours]

Arrival Discharge Rate

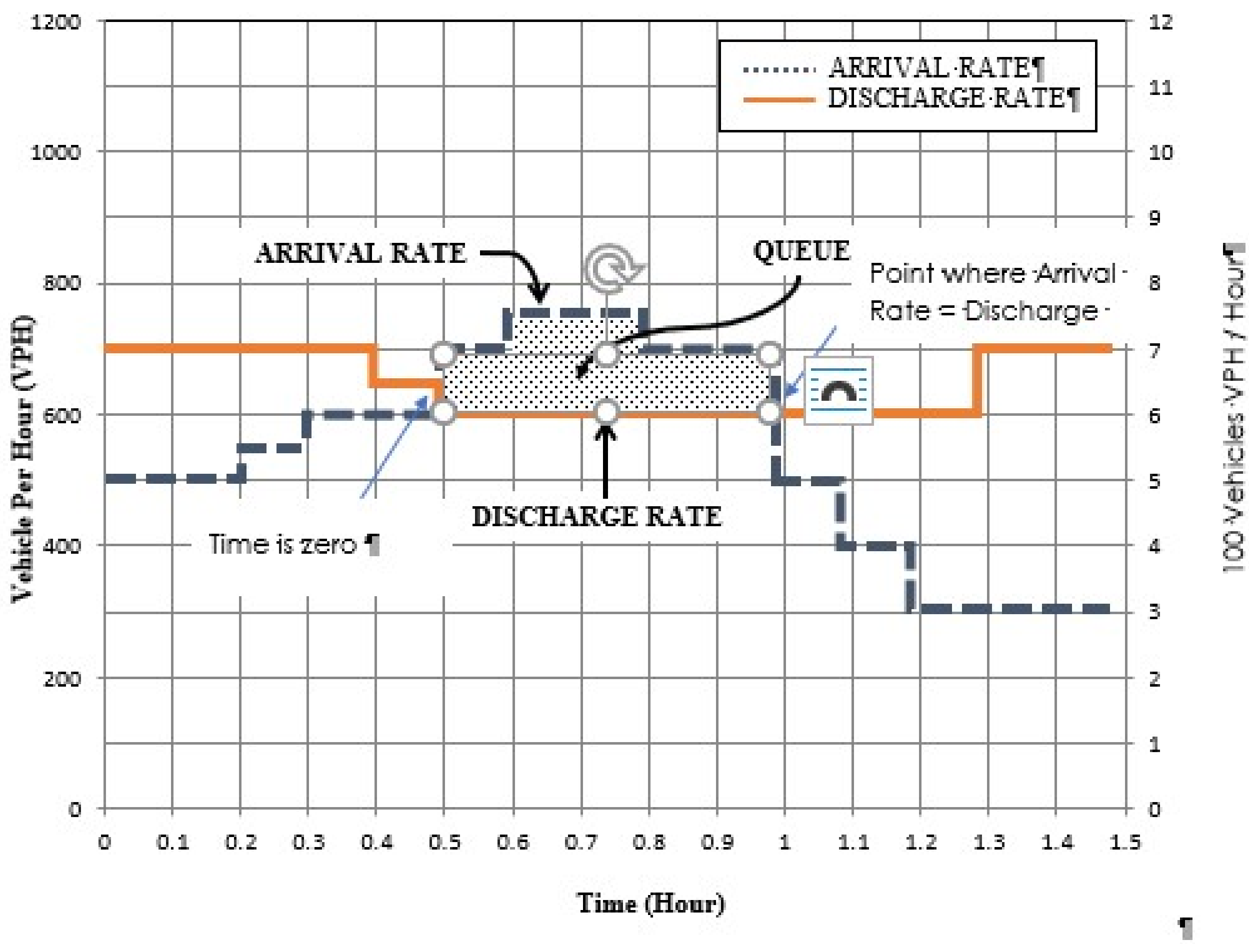
ROUTE ______10______ INTERCHANGE ______BROWN ROAD______
RAMP __NB-EB__

BEGINNING TIME ____0630________ RAMP COUNT DATE __05/10/92______

MAX QUEUE = MAX Δ x 10 = __**6.04** x 10 = 60.4 ≈ 60____ VEHICLES

TOTAL DELAY = ΣΔ = ___26.8________ VEHICLES - HOURS

TOTAL VEHICLES DELAYED = ΣA 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			
Δ = ΣA – ΣB				1.00	2.52	4.04	5.04	**6.04**	5.04	3.04	**0.04**			

MAX Δ

Queue is effectively equal to zero

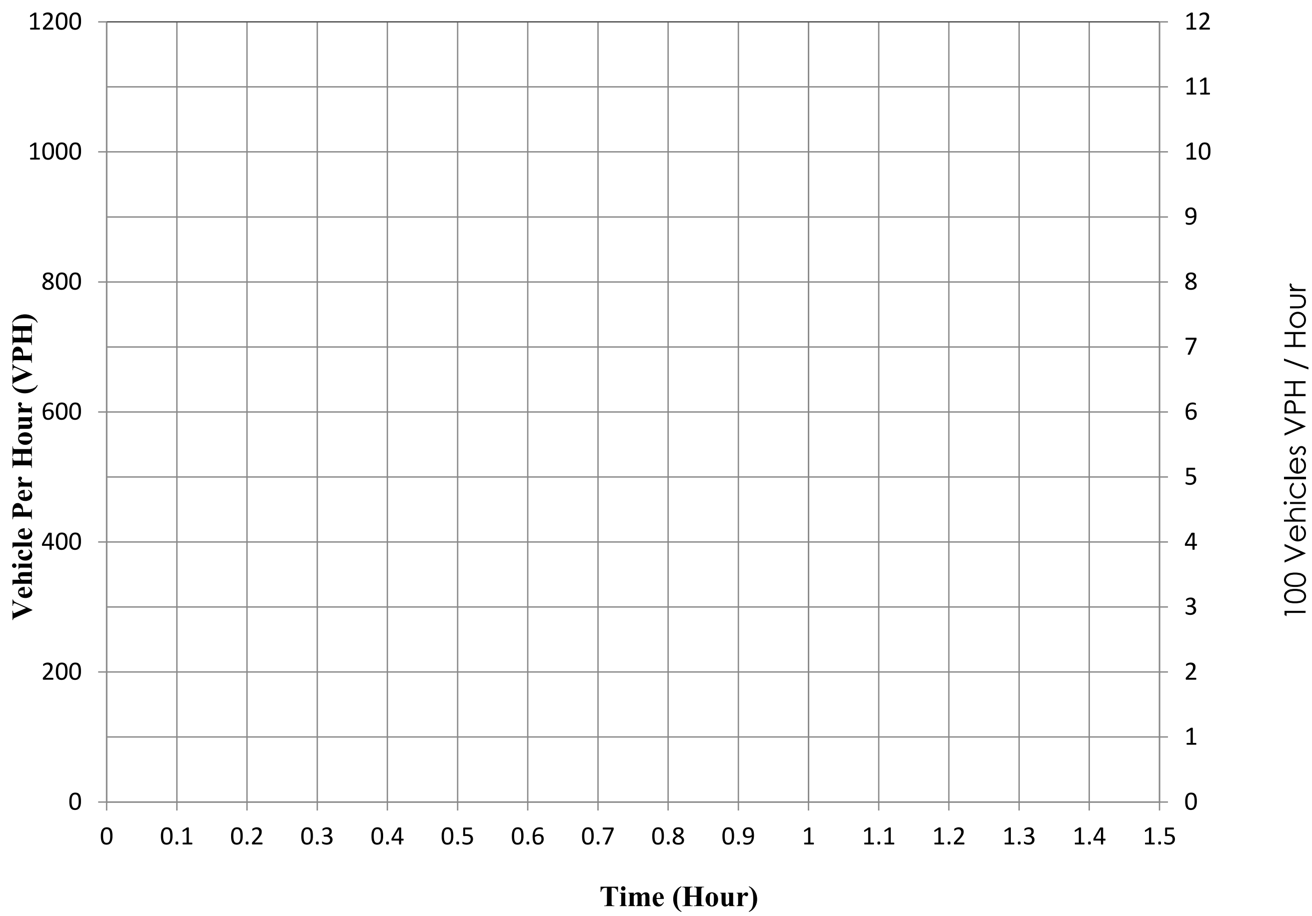
ROUTE _______ INTERCHANGE _____________________________ RAMP _

____

BEGINNING TIME _________________ RAMP COUNT DATE _________________

MAX QUEUE = MAX Δ x 10 = ________________________________ VEHICLES

TOTAL DELAY = ΣΔ = ________________ VEHICLES - HOURS



A. Arrival														
B. Discharge														
Δ = ΣA – ΣB														

Appendix E. 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
CRZ	Clear Recovery Zone
FHWA	Federal Highway Administration
GP Lane(s)	General Purpose Lane(s)
HCM	Highway Capacity Manual
HDM	Highway Design Manual
HOV	High-Occupancy Vehicle
HQ	Headquarters
IP	Internet Protocol
ITS	Intelligent Transportation Systems
MPH	Miles per Hour
MVP	Maintenance Vehicle Pullout
MUTCD	Manual on Uniform Traffic Control Devices
NDOT	Nevada Department of Transportation
NTCIP	National Transportation Communications for ITS Protocol
PR	Project Report
PSR	Project Study Report
PV	Programmable Visibility
RMDM	Ramp Metering Design Manual
RMDP	Ramp Metering Development Plan
RMOM	Ramp Metering Operations Manual
SEC	Second(s)
TMC	Transportation Management Center
TMS	Transportation Management System
VPH	Vehicles per Hour

Appendix F. Glossary

Acceleration Distance: The distance needed for vehicles to accelerate to freeway speeds. For actively metered freeway entrance ramps or connectors this distance is usually measured from the ramp meter limit line to the freeway convergence point (*2013 Managed Lanes and Ramp Metering Manual*, NDOT).

Advance Warning Sign: A sign posted on a ramp (upstream of a ramp meter or along an adjacent arterial) that gives advance warning to motorists of the presence of ramp meters on a ramp or the operational status of ramp meters. (*2013 Managed Lanes and Ramp Metering Manual*, NDOT).

At-Grade Intersection: When the point of crossing of multiple roadways is at the same elevation.

Auxiliary Lane: The portion of the roadway for weaving, truck climbing, speed change, or 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 Traffic 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*).

Blank-Out Sign (formerly Extinguishable Message Sign): A sign that displays a single predetermined message only when activated. When not activated, the sign legend is not visible (*NTCIP 1203 Version V03)*.

Clear Recovery Zone (CRZ): An unobstructed, relatively flat (4:1 or flatter) or gently sloping area beyond the ETW, 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).

Concurrence: Used to express the fact of two or more events or circumstances happening or existing at the same time, agreement, or consistency.

Connector: A length of roadway between two freeways.

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 phase.

Controller: Device that controls the sequence and duration of indications displayed by meters based on algorithms, operator configuration, and field inputs.

Convergence Point: The point of convergence occurs where the right ETW of the entrance ramp or connector is one lane width from the right ETW of the freeway.

Corridor: A network of roadways linking major origins and destinations in a linear pathway.

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

Delay: The time lost while road users are impeded by some element over which the user has no control (*HDM* 62.8).

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). The assumed design speed should be a logical one with respect to the topography, anticipated operating speed, adjacent land use, and functional classification of the highway (*HCM Transportation Glossary*).

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: A device that detects a vehicle's presence and/or other characteristics. The most common detectors are inductive loop detectors located in the pavement and overhead presence detectors located on traffic signal masts. See **Inductive Loop Detectors**. Also see **Passage Detector** (*2013 HOV/Managed Lanes and Ramp Metering Design Manual*, NDOT). For more information see the *FHWA Office of Operations "Traffic Control Systems Handbook" Chapter 6 "Detectors."*

Diagonal Entrance Ramp: Diagonal entrance ramps are almost always one-way and usually have both left and right-turning movements at the at-grade intersection with the minor intersecting road. Diamond interchanges generally have four diagonal ramps *(A Policy on Geometric Design of Highways and Streets, 6th Edition, 2011).*

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: The dividing of a single stream of traffic into separate streams without the aid of traffic control devices.

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 Area: An area used by enforcement personnel to monitor and enforce the compliance with freeway entrance ramp or connector metering signals and HOV preferential lane occupancy requirements.

Entrance Ramp: A ramp that accommodates merging maneuvers onto a freeway.

Exit Ramp: A ramp that accommodates diverging maneuvers off a freeway.

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.

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).

Geometric Design: The arrangement of the elements of a road, such as alignment, grades, sight distances, widths, slopes, etc.

Gore: An area bounded by the edge of the through roadway and the exit ramp, entrance ramp, or connector.

Gore Nose: The triangular shaped area at the merging or diverging end of the gore area. The width at the gore nose at the upstream end is typically between 20 to 30 feet including the paved shoulders, measured between the ETW of the mainline and that of the ramp or connector.

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 (HOV 2+) or three or more (HOV 3+) passengers per vehicle (Chapter 1A, *2014 CA MUTCD*).

HOV Lanes: An exclusive lane for vehicles carrying the posted number of minimum occupants, either part time or full time (*HDM* 62.8).

HOV Preferential Lane: A ramp or connector lane(s) for the exclusive use of vehicles carrying the minimum number of occupants allowed in a HOV.

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).

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.

Lane Line: The line that is used to delineate a lane.

Left: Something located on the left side of a person facing downstream with respect to traffic flow.

Limit Line: A solid white line no less than 12 nor more than 24 inches wide, extending across a roadway traveled way 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 adjacent to the entrance ramp [or connector] shoulder where field personnel can park off the traveled way and access the work site (*HDM* 62.1).

Marking: See **Pavement Markings**.

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: The length of traveled way accomplishing 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 or highway 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*).

Occupancy: The percentage of time that vehicles are present in a detection zone.

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*).

Overhead Sign: A sign that is placed such that a portion or the entirety of the sign is directly above the traveled-way or shoulders such that vehicles travel below it. Typical installations include the following: signs placed on cantilever arms that extend over the traveled-way or shoulders, on sign-supporting structures that span the entire width of the pavement, on mast arms or span wires that also support traffic control signals, and on highway structures that cross-over the roadbeds (Chapter 1A, *2014 CA MUTCD*).

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 mainline and signal 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: All lines, words, or symbols, except signs, officially placed within the roadway to convey regulations, warning, or guidance to vehicle operators.

Peak Hour: That hour during which the maximum amount of travel occurs. It may typically be specified as a morning, afternoon, or evening peak hour (AASHTO*, A Policy on Geometric Design of Highways and Streets, 7th Edition, 2018*).

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

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

Programmable Visibility (PV) Signal Head (or PV Head): Signals heads with special optical lenses and masking that focuses the light coming through the signal lenses, so the view of the signal lenses is restricted to limited directions.

Project Initiation Document (PID): The document that contains a well-defined purpose and need statement. It also contains a proposed project scope tied to a reliable cost estimate and schedule. Any major work on the state highway system regardless of how it is funded requires an approved PID (Chapter 9, *2009* Caltrans *Project Development Procedures Manual*).

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 Detector Entrance Ramp This detector is used for traffic management. Excessive queue detectors are located at the at-grade intersection of metered ramps to detect an excessive vehicle back-up from the ramp metering signal. Intermittent queue detectors are located between the limit line and the at-grade intersection to detect the vehicle back-up from the ramp metering signal.

Ramp Meter: Traffic signal equipment 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 phase (Chapter 9, *2010 HCM*).

Ramp Metering: A vehicular traffic management strategy which utilizes a system of traffic signal equipment on freeway entrance and connector ramps to manage the volume of vehicles entering a freeway to maximize the efficiency of the freeway corridor and thereby minimizing the total delay (*HDM* 62.8).

Ramp Terminal: A junction of a ramp with a surface street where vehicles enter or exit 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.

Right: Something located on the right side of a person facing downstream with respect to traffic flow.

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: The portion of the highway included between the outside lines of the sidewalks, or curbs and gutters, or side ditches including 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 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.

Shall: Used to express futurity, determination, inevitability, command, and requirement.

Should: Used to indicate obligation, duty, correctness, and what is probable.

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 (*2013 Managed Lanes and Ramps Metering Manual*, NDOT).

Sign: Any traffic control device that is intended to communicate specific information to road users through words or symbols. Signs do not include highway traffic signals, pavement markings, delineators, or channelizing devices (*HDM* 62.8).

Sign Legend: All messages, logos, pictographs, symbols, and arrow designs intended to convey a specific meaning. The border, if any, on a sign is not considered to be a part of the legend (Chapter 1A, 2014 *CA MUTCD*).

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 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*).

Spacing: The distance between two successive vehicles in a traffic lane, measured from the same common feature of the vehicles, such as vehicles' 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).

Storage: The number of vehicles in a queue waiting to proceed.

Storage Length: The length of traveled way, such as an entrance ramp or connector available for storing queued vehicles.

Taper: A ratio at which traffic lane width longitudinally reduces or increases. See Taper Ratio).

Taper Ratio: A mathematical expression of the ratio of longitudinal traveled-way length to transverse lane width.

Traffic: A general term used to refer to the passage of people, vehicles and/or bicycles along a transportation route (*HDM* 62.8).

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).

Traffic Signal: A power-operated control device by which traffic is warned or directed to take a specific action. These devices do not include signals at toll plazas, power-operated signs, illuminated pavement markers, warning lights, or steady burning electrical lamps (*HDM* 62.8).

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 CHP and other transportation and emergency response organizations (*DD 70*).

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 making a designated turn at an intersection.

Type 1 Standard: See Caltrans Standard Plan ES-7B *Electrical Systems, Signal and Lighting Standard, Type 1, and Equipment Identification Characters*.

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

Vehicle: A device used to move, propel, or draw a person upon a highway, except a device on rails or propelled exclusively by human power. This definition, abstracted from the California Vehicle Code, refers to motor vehicles excluding those devices necessary to provide mobility to persons with disabilities (*HDM*, Page 60-14).

Vehicle Occupancy: The number of people in a car, truck, bus, or other vehicle (*2013 Managed Lanes and Ramps Metering Manual*, NDOT).

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

Appendix G. Bibliography

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