5 INTERSECTIONS AND INTERCHANGES

Conflicts between bicyclists and turning or merging vehicles at intersections and interchanges are a major threat to bicycle safety. This chapter addresses best practices for the most common situations.

IN THIS CHAPTER:

5.1 RIGHT TURNS AND RIGHT-TURN ONLY LANES:

Many traffic collisions are caused by a motorist's improper turn or not yielding the right-of-way to the bicyclist. A common situation is on the intersection approach where a motorist's right-turn path crosses the path of a bicyclist proceeding straight. This is a concern with and without dedicated right-turn only lanes.

Design Considerations - Intersections Without Right-Turn Only Lanes

In this situation, the bicyclists and the right-turning vehicle share the same lane; when there is a bike lane, motorists must enter the bike lane per CVC. When there is no bike lane, motorists must turn as close as practicable to the right curb per CVC 22100a(1); this also discourages cyclists from continuing to ride on the right-hand side of the right-turning vehicles. Right-turning motorists must use their turn signals so that cyclists will know their intent. Cyclists should maneuver to the left side of the right-turning vehicle as soon as feasible. In any case, right-turning motorists must yield to any cyclist who may be on their right.

This bicyclist is correctly positioned in between through and right-turning traffic.

Design Considerations - Intersections With Right-Turn Only Lanes

Right-turn only lanes present two particular difficulties to bicyclists:

- Through bicyclists are forced to weave with right-turning motor-vehicle traffic in order to position themselves correctly; and
- Lane widths are commonly narrowed in order to stripe a new right-turn-only lane, often eliminating the bike lane if any. This forces bicyclists and motorists to share an even narrower through lane; as a result, some through bicyclists will ride inappropriately on the right side of the right-turn lane.

The weaving cannot be eliminated, but it can be made safer by increasing the awareness of the right-turning motorists to the presence of bicycles, by slowing motor vehicle traffic and by educating bicyclists about the correct position from which to ride straight through the intersection.

DESIGN CONSIDERATIONS

Curb radii that have been designed to facilitate a high speed right turn are invariably undesirable from the point-of-view of both bicyclists and pedestrians. In many cases, the benefit of a high speed right turn is marginal as the motorist is subject to STOP or signal controls soon after the turn is made. In other cases, such as freeway on-ramps, the ramp is long enough to enable the motorist to accelerate to the desired freeway speed.

MUTCD R4-4

Guidance for the following typical right-turn lane designs is presented in this section:

5.1.1 Typical right-turn only lane;

5.1.2 Bike Lane approaching T-Intersection

5.1.3 Channelized right-turn lane;

5.1.4 Free right-turn lane;

5.1.5 Dual right-turn lanes with shared through/right lane.

This bicyclist has correctly positioned himself to go straight through the intersection with respect to the right-turn only lane.

5.1.1 Typical Right-Turn-Only Lanes

Caltrans Standard - Roads with Bike Lanes

The bike lane shall be provided to the left of the right-turn only lane. See MUTCD Figures 9C.4 and 9C.5 for typical illustrations of right-turn lanes and bike lanes.

VTA Best Practice - Roads with Bike Lanes

The bike lane line should be dropped and replaced with a dotted bike lane line 100 feet (for speed limits of 30 mph or less) to 200 feet (for speed limits of 35 mph or more) in advance of the right-turn lane, as shown below in Figure 5-1.

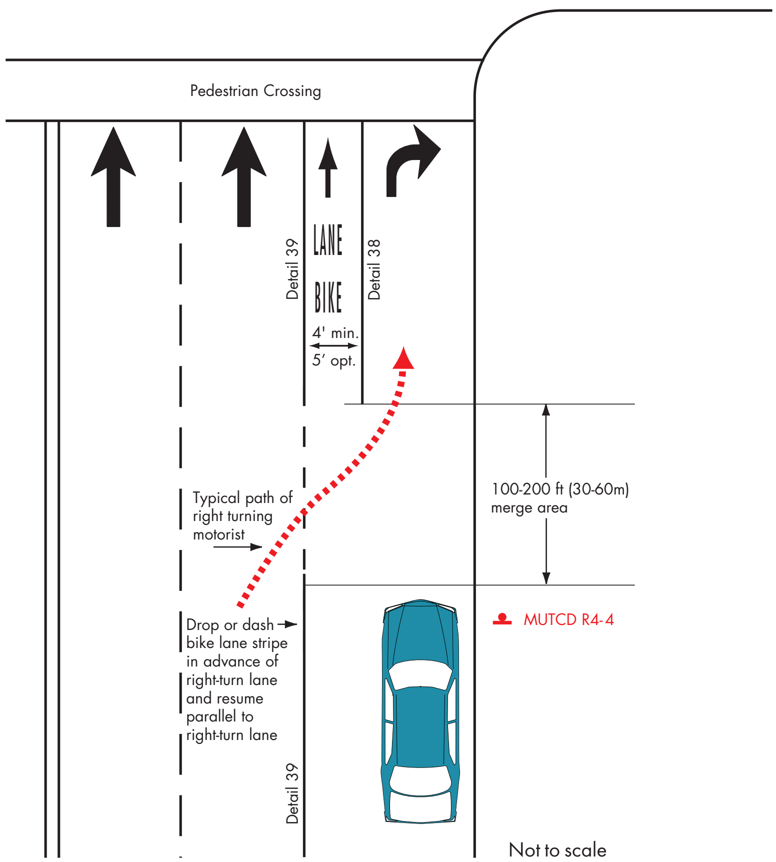


Figure 5-1:
Bike Lane Striping at Right-turn Only Lane

This bike lane on Tully Road enables bikes to pass the queue of right-turning cars in the right-turn only lane.

NOTE

CVC 22100 (a) (1) Both the approach for a right-hand turn and a right-hand turn shall be made as close as practicable to the right-hand curb or edge of the roadway...

VTA Best Practice- Insufficient Roadway Width for Bike Lane and Right-Turn Lane

Design Considerations

When a bike lane approaches a right-turn lane, and there is insufficient roadway width to stripe both the bike lane and the right-turn lane, the key concept to convey is that there must be a weave between through bicyclists and the right-turning vehicles, as discussed in Section 5.1.1. A bike lane should not be terminated abruptly or eliminated in order to add a right-turn lane.

If a bike lane is being added to a location where there is insufficient roadway width for both the bike lane and the right-turn only lane, then consider one of the options discussed below.

VTA Best Practice

There are several striping options to help inform motorists and cyclists of these issues. The optimal solution will depend on the relative volumes of through and right-turning vehicles, the number of heavy vehicles proceeding straight and turning right, and the posted speeds. Options are:

(1) Narrow the through lanes and turn lanes to 11 feet (10 feet if posted speeds are 30 mph maximum) in order to fit a four-foot bike lane as shown in Figure 5-1; consider this option where the traffic has low percentage of heavy vehicles and where it is not a bus route.

(2) Provide approximately equal width through lane and right-turn lane and place a dashed outline of a bike lane on the left side of the right-turn lane. (Consider this option where the right-turn motor vehicle volume is heavy only for one peak period and the remainder of the day, cyclists could choose to go through from the left side of the right-turn lane. This will educate cyclists to not hug the curb and risk getting involved in the right hook collision described above, and will educate motorists that through cyclists may be present in the right-turn only lane.

(3) Provide a 14-foot wide through lane and place a Shared Roadway pavement marking on the right side of the through lane. See Figure 5-2.

(4) Provide approximately equal width through lane and right-turn lane and place a sharrow on the left side of the right-turn lane; see Figure 5-3. Consider this option only if both:

(a) the through and right-turn motor vehicle volumes are relatively equal in both peak periods; and

(b) either (i) the through motor vehicle speeds and volumes are relatively low or (ii) if the through speeds are above 30 mph, there are at least two through lanes.

(5) Provide one wide bike lane in lieu of the right-turn only lane, as shown in Figure 7-5, recognizing that in California, right turns will be made from the bike lane, effectively creating the same situation of the right-turn only lane with no Bike Lane. This may be appropriate with lower through and turning volumes and speeds.

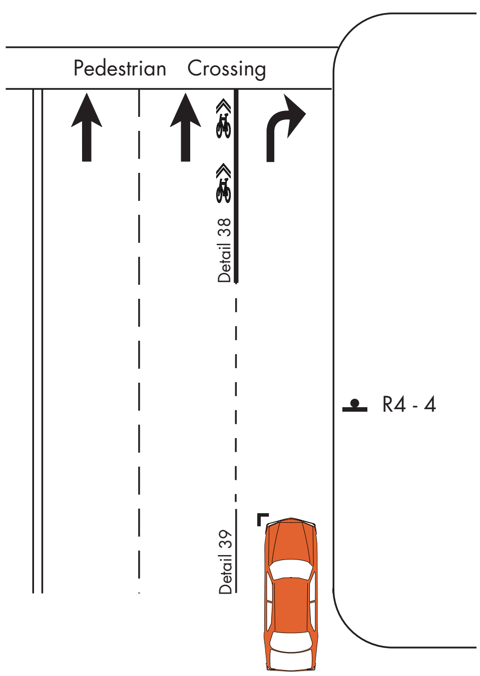


Figure 5-2
Dropped Bike Lane at Right-turn Only Lane-option 3

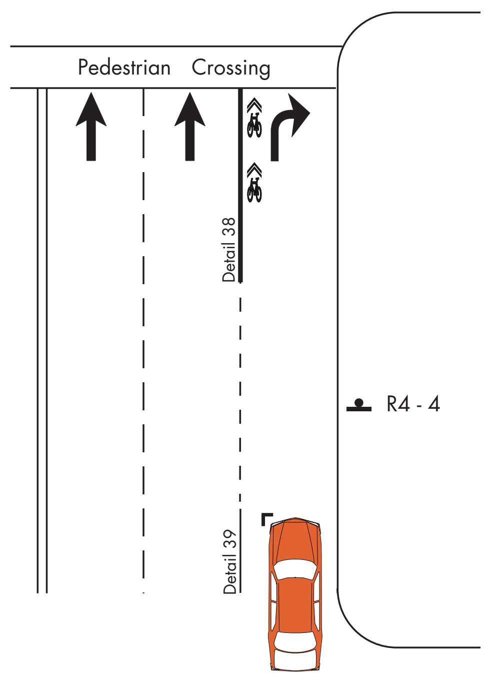


Figure 5-3
Dropped Bike Lane at Right-turn Only Lane-option 4

Oakland Right-Turn Lane with Bike-Right-Turn Lane

5.1.2 Bike Lane Approching T-Intersection

VTA Best Practice

Approaching a T-intersection, the bike lane is placed in between the left-turn only and right-turn only lanes. The bike detector and bike detector symbol is placed as indicated in Figure 5-4. In locations with heavy right-turn volumes, a right-turn only bike lane can also be provided to the right of the right-turn only lane.

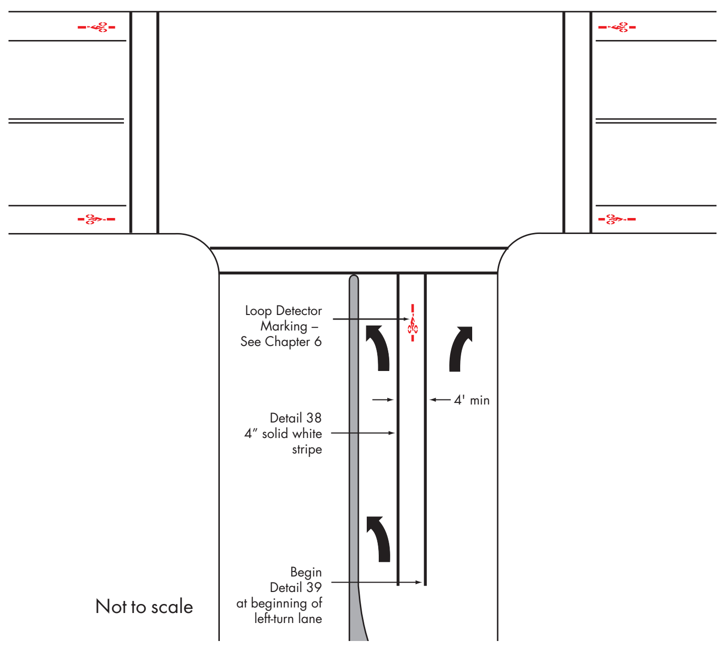


Figure 5-4:
Bike Lane Striping at T-intersection with Right-Turn and Left-Turn lanes

5.1.3 Channelized Right-Turn Lanes

If used, channelized right-turn lanes should be designed so that right-turning vehicles must slow sufficiently before they reach the crosswalk. The design should enable the motorist to easily turn his/her head to the left to look for oncoming traffic. STOP control should be considered instead of YIELD control to improve the safety of pedestrians. (See Figure 5-5). When intersections are renovated or reconstructed, it is best to eliminate the “pork chop” island and bring the right-turn movement under signal control.

See Section 5.3.4 for a discussion of Channelized Right-Turn Lanes at freeway interchanges.

Pork-chop islands can be problematic for bicycles due to odd angles and high speed traffic.

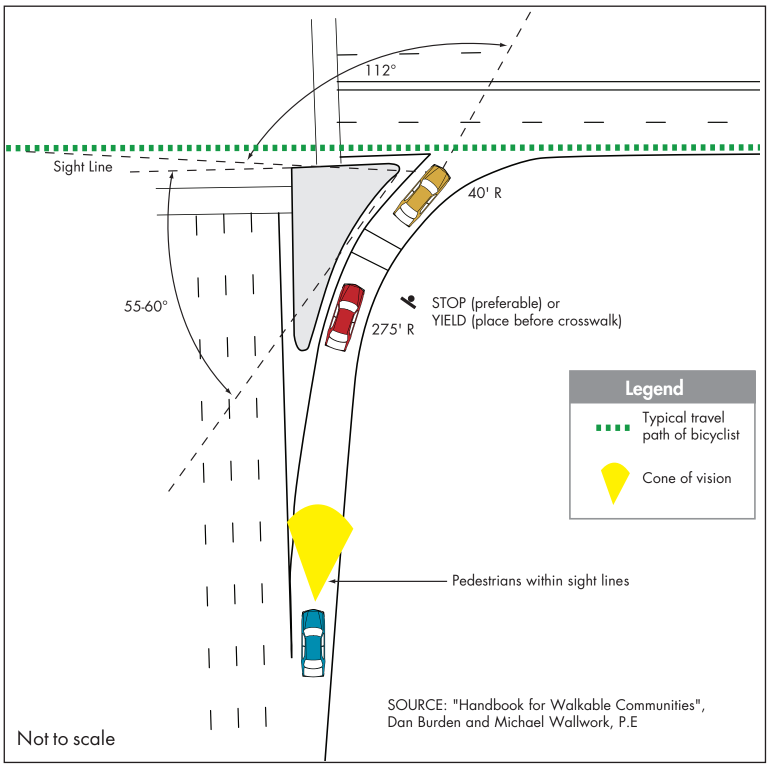


Figure 5-5: Right-Turn Channelization Island

TECH TIP

At locations with existing islands, one or more of the following can be done to reduce conflicts:

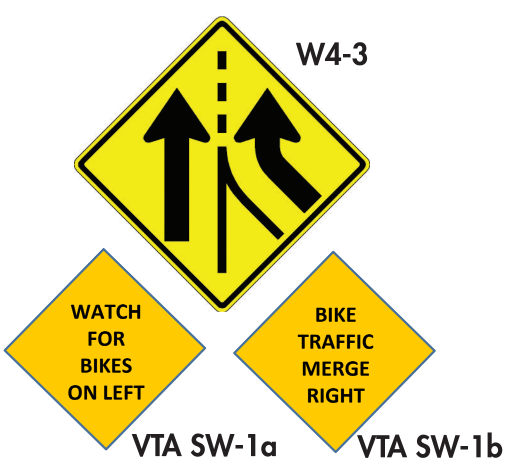
1. Modify island to slow turning traffic as shown in Figure 5-5.
2. Bring turn under signal control or install stop sign prior to the crosswalk.
3. Eliminate island and redesign curb with a curb radius of 40 feet maximum, if a truck route, 25 feet maximum, if not a truck route.

An approaching bicyclist would find himself to the left of this automobile entering from the cross street with a free right-turn lane.

TECH TIP

Options to improve the awareness of motorists in a free-right-turn lane of conflicting paths of pedestrians and bicyclists:

1. Design island to reduce speed of turning vehicles as shown in Figure 5-5.
2. Install Yield/Stop sign prior to crosswalk.
3. Install bike-activated flashing yellow beacon as indicated in Figure 5-6.
4. Provide Bike Lane (optimally) or 15 feet min. width in the southbound through lane at far side of intersection adjacent to the island.



5.1.4 Free Right-Turn Lane(s)

Free right-turn lanes, (i.e. when the roadway is striped in such a manner that a fast merge from the right receives its own lane after the turn), puts the through bicyclist at risk. The free right-turn lane design results in the through bicyclist being sandwiched in between two through lanes of high-speed traffic. This practice should be avoided on designated bikeways, including cross county bicycle corridors. Existing installations should be ameliorated by slowing the speed at which vehicles make the right turns as discussed in Section 5.1.2 and by installing warning signs and a “YIELD” or “STOP” sign for the merging traffic, located prior to the crosswalk to the island, as illustrated in Figure 5-6. Also, if a bike lane is not provided, the approaching through lane should be wide enough (15 feet) for bicycles and cars to share. See Chapter 5.3.5 for a discussion of free right-turn lanes at freeway interchanges.

VTA Best Practice

Free right-turn lanes should not be provided in new construction. Existing free right-turn lanes from one arterial onto another should be controlled by a “STOP” sign in advance of the crosswalk, and a “YIELD” sign in advance of the bicycle merge point. Figures 5-6 and 5-7 illustrate how to modify an existing free right-turn lane to be safer for bicyclists and pedestrians.

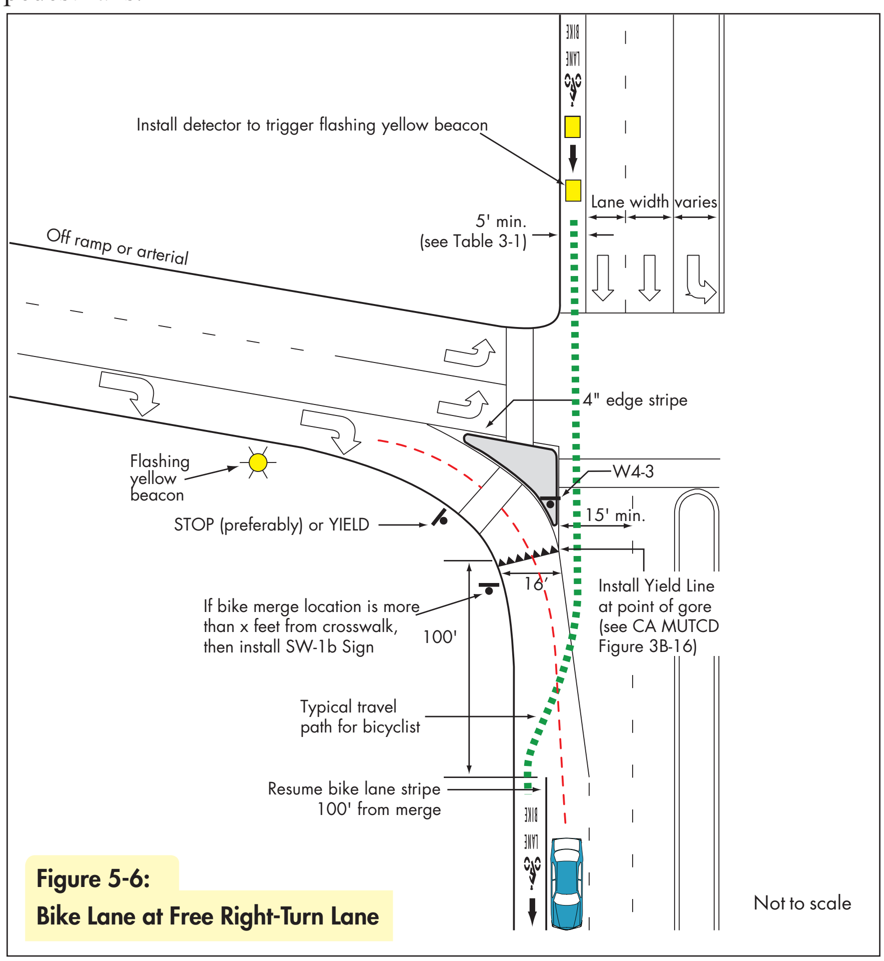
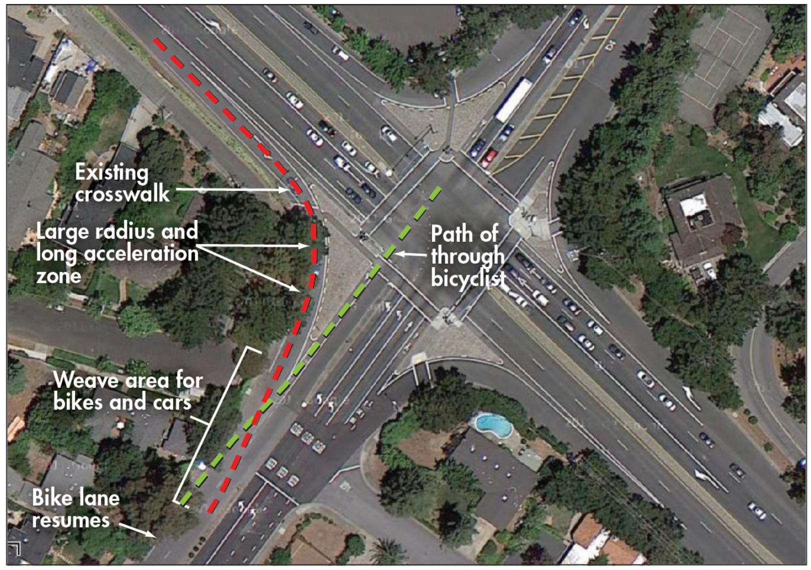


Figure 5-6: Bike Lane at Free Right-Turn Lane

Figure 5-7:
Bicycle Accommodation Issues at Free Right-Turn Lanes

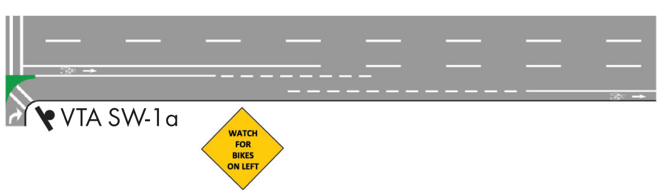


Merging at Free Right-Turn Lanes: Typical Condition

Options for Weaving Area at Free Right-Turn Lanes.

OPTION 1:
Green Transition Zone

OPTION 2:
With Room to Carry Bike Lane



5.1.5 Dual Right Turns with Shared Right/Through Lane

Caltrans Standard

HDM§ 403.6(1) states that: *optional right-turn lanes should not be used in combination with right-turn-only lanes on roads where bicycle travel is permitted. The use of optional right-turn lanes in combination with right-turn-only lanes is not recommended in any case where a Class II bike lane is present.*

VTA Best Practice

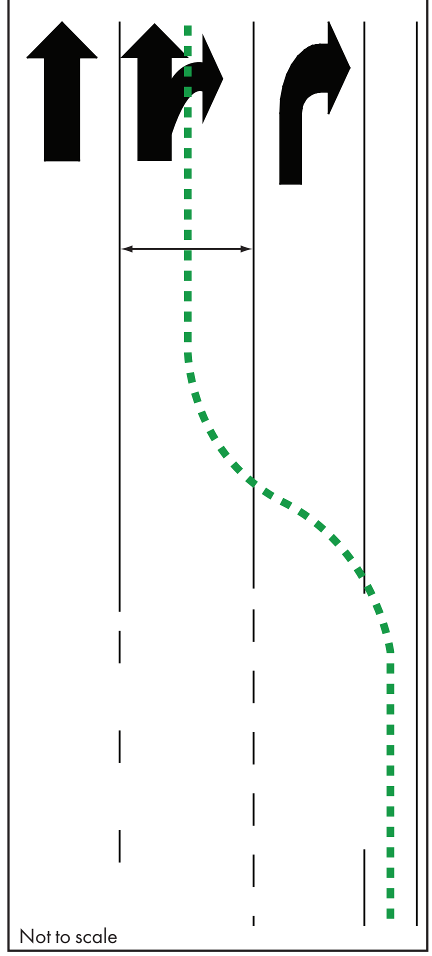
As stated above, the shared right-turn lane with the right-turn-only lane should not be used. VTA Best Practice is to not install this striping configuration with any new roadway, roadway restriping, project mitigation or other future condition. Where this configuration exists, VTA Best Practice is to prioritize removing them as follow:

- on roadways with a posted speed limit above 35 mph;
- on roadways with bike lanes since a bike lane cannot be striped up to the limit line, as depicted in Figure 5-8.

Design Considerations

When a dual right-turn lane is provided by creating a shared right-turn and through lane adjacent to a right-turn only lane, it is impossible to provide bike lanes at the intersection approach. Due to the uncertainty the bicyclists are faced with on the direction the motorist in the shared lane will be going, the bicyclist can only rely on the motorist using his/her right-turn signal. Without knowing whether the motorist is going to turn right or proceed straight, the bicyclist cannot position him/herself correctly in order to avoid being turned into by a right-turning vehicle from the shared lane. For example, if the motorist in the shared lane is proceeding straight, the cyclist could ride in between the right turn lane and the shared lane. If the motorist is turning right, the cyclist could be one lane over to the left of the right-turning vehicle. In either case, the cyclist could (and when in doubt, the cyclist should) ride in the center of the shared through/right lane as depicted in Figure 5-8.

Figure 5-8:
Travel Path of Cyclist at Right-Turn Lane plus Optional Right-Turn Lane



R3-7R

These optional dual right-turn lanes present difficulty for bicyclists proceeding straight.

Typical left-turn pocket at a signalized intersection.

5.2 LEFT TURNS AND LEFT-TURN ONLY LANES

Left turns at intersections present difficulty to bicyclists in two ways: conflicts with left-turning motorists and the difficulty experienced by a bicyclist in executing a left turn.

Improper left turns by motorist are often one of the chief causes of collisions at intersections (violation of California Vehicle Code [CVC] 21801). Often motorists are concentrating on finding a gap in vehicular traffic that they fail to notice oncoming bicycle traffic. Potential countermeasures are to:

- Provide left-turn pockets
- Provide protected left-turn signal phasing
- Improve intersection design to improve visibility of the left-turning motorist to the oncoming bicyclist. A bicyclist riding to the extreme right of a wide intersection, for example, may be difficult to see by the motorist.

5.2.1 How Cyclists Make Left Turns

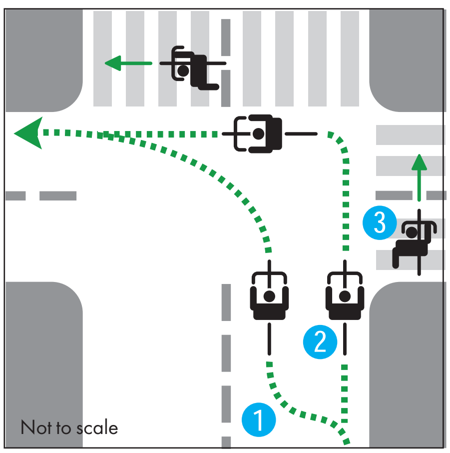


Figure 5-9:
Left-turn Options for Bicyclists

Left-turn option depends on bicyclist's ability and traffic conditions

Left turns by bicyclists can be made in three ways, succinctly described as take the lane; square the corner or walk the bike. These are illustrated in Figure 5-9 and described below.

1 **Take the Lane-**The bicyclist would signal the intention to turn left, look over his/her shoulder, and if clear, move over to the left-turn lane, if there is one, or the center of the left-most through lane, to wait for a gap in traffic. This type of crossing is usually favored by experienced cyclists at all types of intersections. If it is a signalized intersection, see Chapter 6 for guidance on providing signal detection that will detect bicycles.

2 **Square the Corner-**The bicyclist would proceed straight through the intersection, then stop at the far side, turn 90 degrees, and proceed as if he/she were now proceeding straight on the side street. This type of crossing is usually favored by moderately experienced cyclists at busy intersections, or casual cyclists at uncomplicated intersections. Depending on whether the intersection is signalized or controlled by stop signs, the bicyclist may need to wait through an entire signal cycle or wait for adequate gaps in traffic.

3 **Walk the Bike-**This type of crossing is usually favored by casual or beginning cyclists at signalized intersections. The bicyclist would either ride through the intersection and stop at the far side or dismount and walk in the crosswalk. On the far side the bicyclist would push the pedestrian push-button at signalized intersections, (if there is one) or wait for a gap in traffic at unsignalized intersections and walk across in the crosswalk.

VTA Best Practice

A left-turn only bike lane should be considered when an average of two bikes per signal cycle are present during the peak hour.

5.2.2 Bike Lane at Left-Turn Only Lanes

Caltrans Standard

When a left-turn bike lane is provided, it shall be provided to the right of the right-most left-turn lane (see Figure 5-10) per HDM and the AASHTO Guide. See also MUTCD Figure 9C-1.

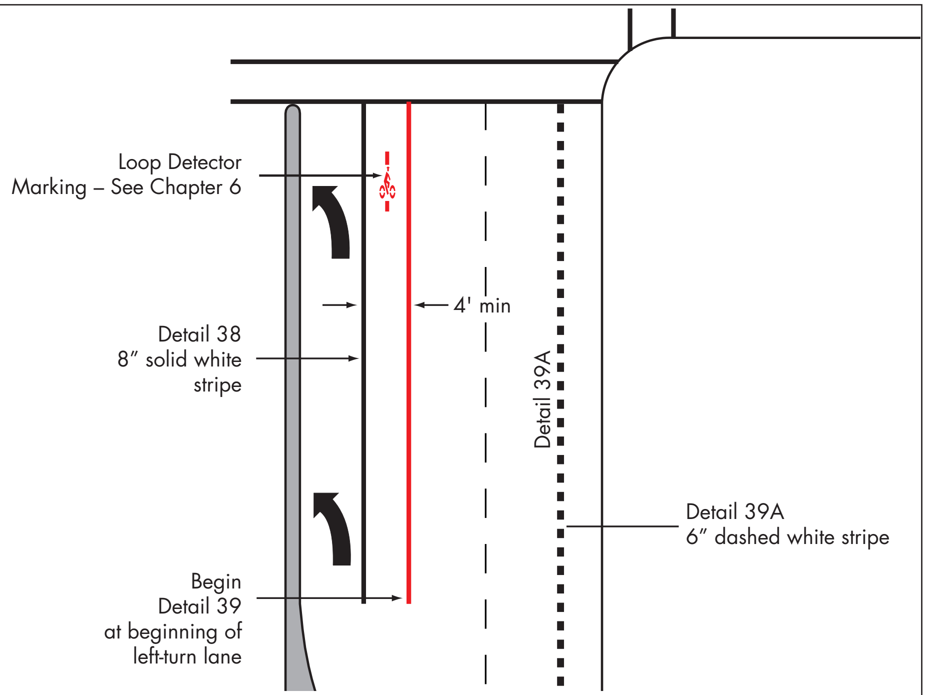


Figure 5-10:
Bike Lane Striping at Left-turn Only Lane

5.3 FREEWAY INTERCHANGES

This section discusses the elements of freeway interchange design that most affect bicyclists:

5.3.1 Freeway interchange and ramp geometry best practices

5.3.2 Bike lanes through an older-style interchange

5.3.3 Retrofitting free flow ramps and cloverleaf interchanges

5.3.4 Auxiliary lanes through freeway interchanges

5.3.5 Free right-turn lanes at freeway interchanges.

Typical Type L-9 freeway interchange of the 1960's designed with only motor vehicle traffic flow in mind; new and modified partial-cloverleaf interchanges should look like Figure 5-12 instead.

5.3.1 Interchange and Ramp Design

Design Considerations

In the past, many ramp junctions with arterials were designed to facilitate a high speed merge or diverge. It is illegal for the motor vehicle to maintain the high freeway speeds once on the arterial, and the high speeds unnecessarily expose bicyclists (and pedestrians) to risk of serious injury. Similarly, it is illegal to accelerate to freeway speeds while still on the local roadway.

Most of the conceptual interchange configurations illustrated in HDM §502.2 per the 2012 Complete Streets revisions have diamond T-style ramp intersections (e.g. Types L-1, L-2, and the off-ramps in L-7, L-8, L-9) and/or loop J-style ramp intersections (e.g. Types L-7, L-8). These are depicted in Figure 5-11. The slower speeds resulting from these intersection designs improve bicycle and pedestrian access and safety compared to the free-flow ramps with high speed connections formerly favored by Caltrans. A discussion of options to retrofit high speed ramps is presented in Section 5.3.3.

A promising interchange configuration is the diverging diamond, where right turns onto the on-ramps are replaced with left turns by swapping the lanes. Single Point Urban Interchanges (SPUI), however, are not bicycle-friendly and should not be used.

Caltrans Standard

There is no single standard for interchange configuration or ramp intersection type; the appropriate interchange configuration is determined based on site-specific conditions, traffic volumes and engineering judgement.

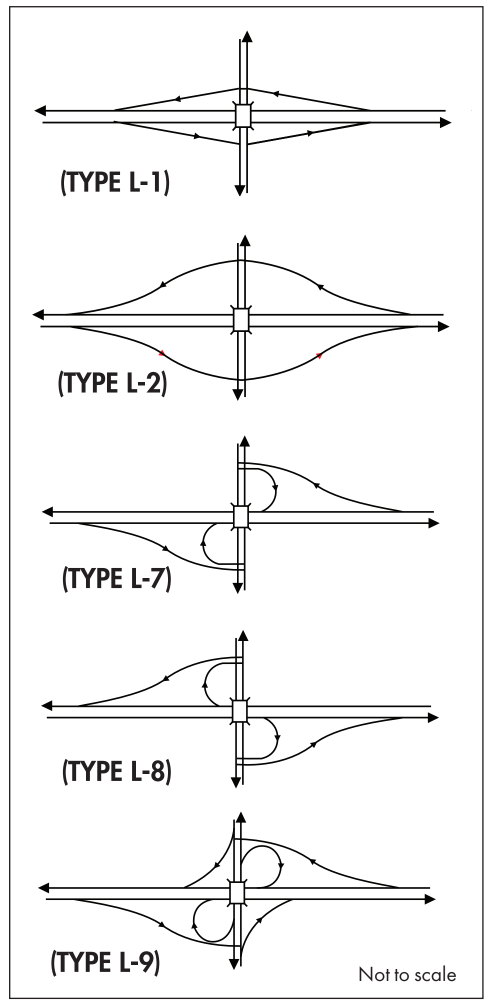


Figure 5-11:
Typical Local Street/Freeway Interchanges

Source:
Figure 502.2 Highway Design Manual

1 See also CDT practice 4-26. AASHTO Green Book Chapter10 says to design at-grade ramp terminals as intersections as given in the Green Book Section 9.6.

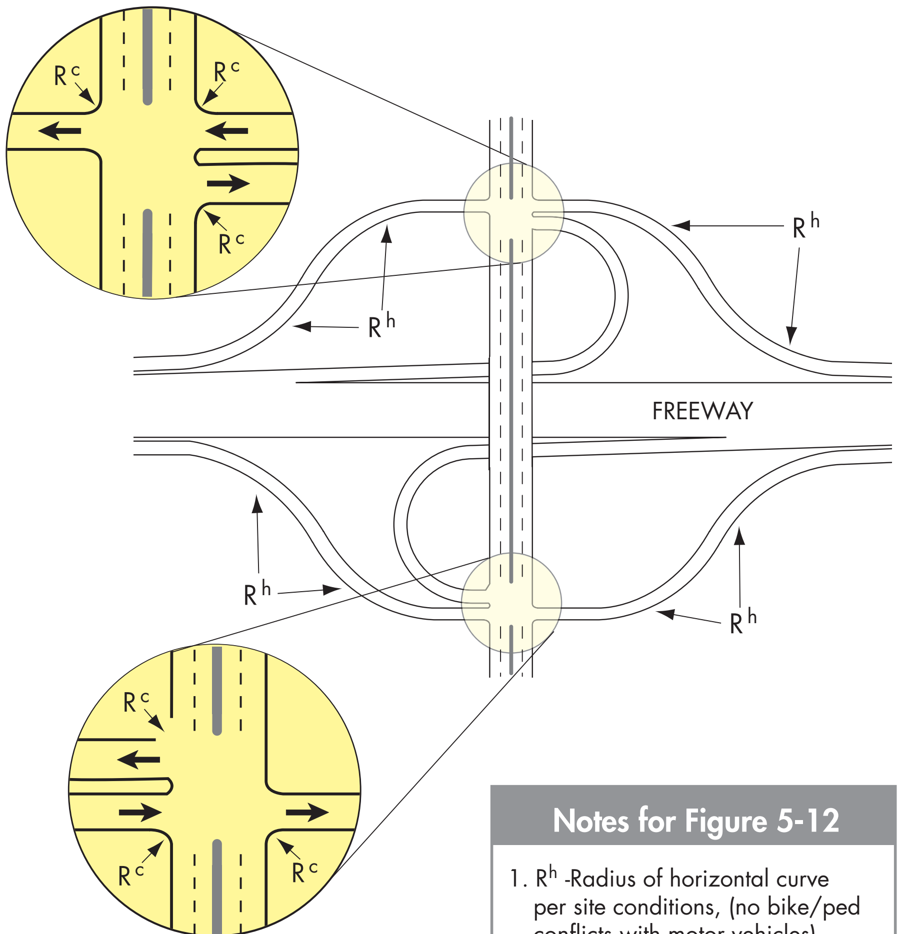
TECH TIP

The ramp intersection with the local street may also be controlled by a modern roundabout; see Design Information Bulletin 80-01, Roundabouts, Caltrans Division of Design, October 3, 2003 and Roundabouts: An Informational Guide FHWA Report Number FHWA-RD-00-067, June 2000, for more information.

To enhance bicyclist and pedestrian safety, all new interchange construction or modifications in Santa Clara County are to be designed as follows: 1

- Ramp intersections with local roads are 90-degree intersections rather than free flow ramps with high speed connections.
- The curb radii Rc of the ramp intersection should be such that the right turns are made at a slower speed, i.e. 15 mph.
- Posted speed of local roadway or arterial is 35 mph maximum.
- The off-ramp traffic is controlled with either stop sign or traffi signal (see sidebar).
- Maximum grade on over/under crossing is 5%.
- If local road is an undercrossing, the undercrossing is well lit for daytime as well as nighttime conditions.

A Type L-9 interchange configuration with on- and off-ramp termini as 90-degree intersections is illustrated in Figure 5-12.



Notes for Figure 5-12

1. R^h -Radius of horizontal curve per site conditions, (no bike/ped conflicts with motor vehicles)
2. R^c = Curb radius at ramp terminal intersections to be 20 -25 feet maximum for optimum ped bike accommodation.
3. Posted speed limit on Arterial - 35 mph maximum.

Not to scale

Figure 5-12: VTA Best Practice Freeway Interchange

LOCAL TIP

The ramps at the Hwy101/Tully Rd. interchange in San Jose were designed with turning truck design speeds of 15-18 mph.

TECH TIP

Options for retrofitting/modifying existing interchanges with free flow ramps are illustrated in Figures 5-13 and 5-14.

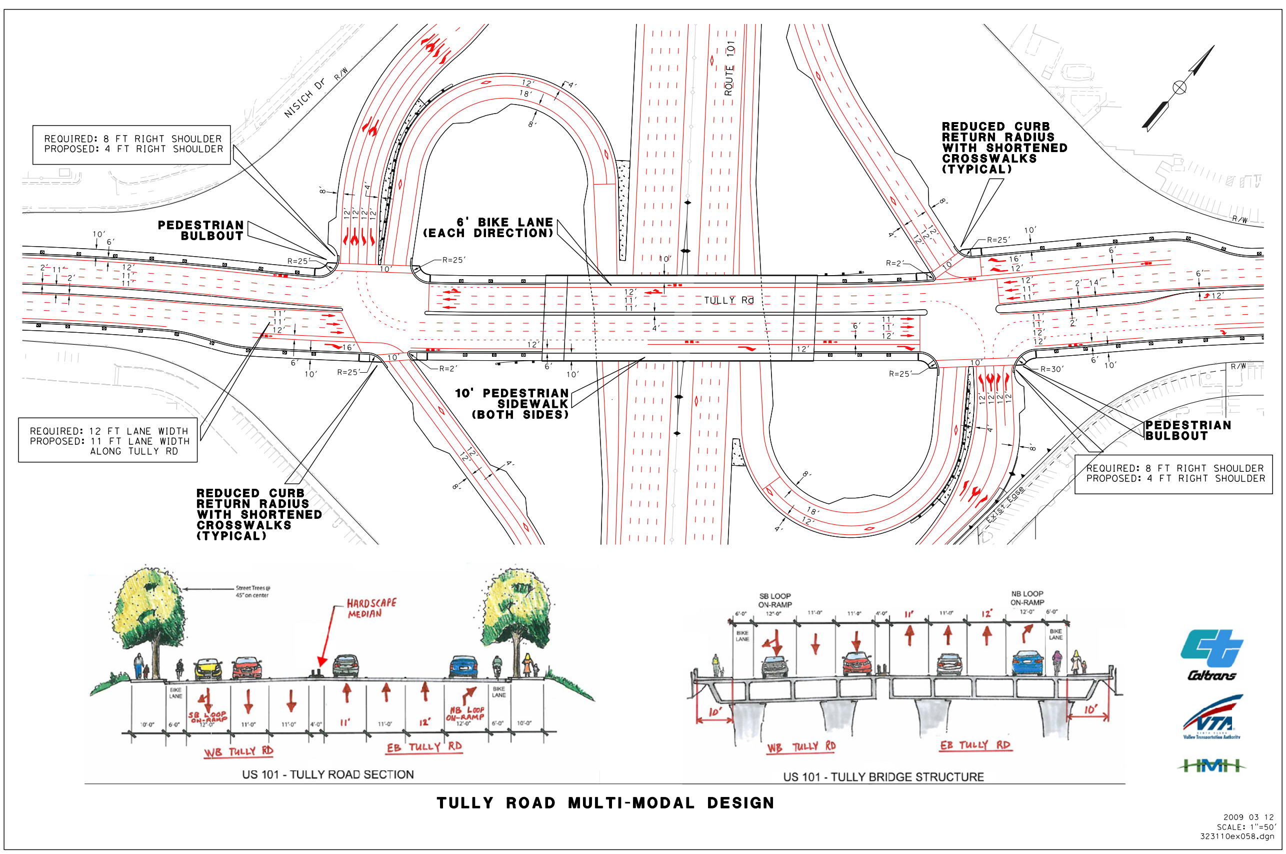
5.3.2 Bike Lanes Through Freeway Interchanges

New Construction or Reconstruction

Accommodating bicyclists through newly built freeway interchanges should not be much different than at any other heavily travelled arterial intersection. The high traffic volumes may intimidate many potential bicyclists, but the speeds and the geometry will be similar to standard at-grade intersections as long as the interchange is designed to current HDM Complete Streets standards, including:

- Ramp termini have 90-degree intersections with a 40-foot maximum curb radii.
- Stop or signal-controlled movements onto and off of the ramp.
- Turning speeds of 15 mph maximum for any ramp that is not designed as a 90-degree intersection.
- Width for bike lanes on the local road through the entire interchange.

When bike lanes are provided at such an interchange, with relatively short right-turn lanes at 90-degree intersections, see Figure 7-4 and also CA MUTCD Figures 9C-4 to 9C-6.



Autocentric Freeway Interchanges

Bicycling through many freeway interchanges designed in past decades is challenging due to free-flow ramps and often no shoulders let alone bike lanes. Bicyclists will naturally ride in the shoulder if there is one and if it is free of debris. Four-leaf clover interchanges are the most challenging since they present four weave points in each direction of travel.

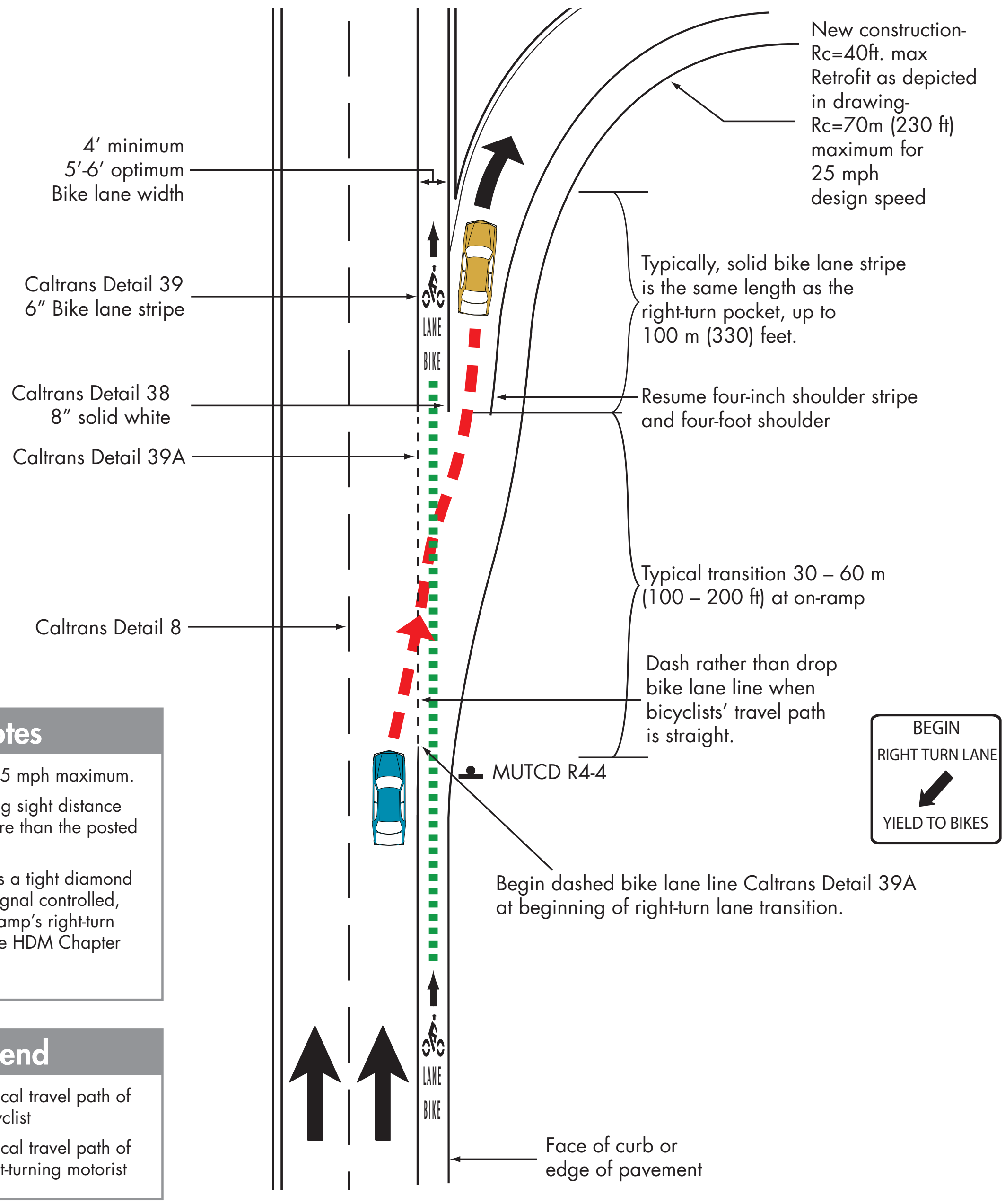
In providing a bike lane through an interchange with free-flow ramps, the designer must consider where to drop or dash the bike lane stripe in advance of the on-ramp to indicate the weaving area between cyclist and motorist. Faster traffic running speeds would tend to call for a longer dashed section. With some interchange configurations, there are two on-ramps to traverse in each direction of travel, calling for two dashed sections of bike lane. Suggested bike lane striping is shown in Figures 5-13 and 5-14 for two right lane situations: Figure 5-13 illustrates a typical situation with an added right-turn lane and Figure 5-14 illustrates the situation for a trap right-turn lane.

One difference between some freeway ramps and high volume arterials is the sheer volume of turning traffic. Santa Clara County has many locations where the right-turning volume onto or off of a freeway ramp approaches 2000 vehicles per hour, resulting in designers calling for extra long right-turn lanes and/or double right-turn lanes. When there is such a right-turn only lane and a bike lane, the bike lane drop / dash must be considered with respect to the right-turn lane delineation, so that the cyclists has time to move to the left of the right-turn lane, at a point where motorists are not distracted by other decisions they need to make. Suggested dimensions are shown in Figures 5-13 and 5-14.

Free-flow ramps are intimidating to pedestrians as well.

Even with a bike lane, these weave areas at freeway on-ramps are challenging due to the angle of the ramp departure from the roadway.

This bicyclist approaching an interchange has to squeeze between the through lane and the right-turn lane since there is no bike lane.



Notes

1. Posted speed 35 mph maximum.
2. Provide stopping sight distance for 10 mph more than the posted speed.
3. If interchange is a tight diamond or ramps are signal controlled, design the on-ramp's right-turn lanes per Figure HDM Chapter 400.

Legend

Typical travel path of bicyclist

Typical travel path of right-turning motorist

VTA Best Practice

This treatment is suggested as an interim measure until funding becomes available to retrofit the ramp geometry to be more bicycle and pedestrian friendly as shown in Figures 5-6, 5-12, 5-15 and 5-16.

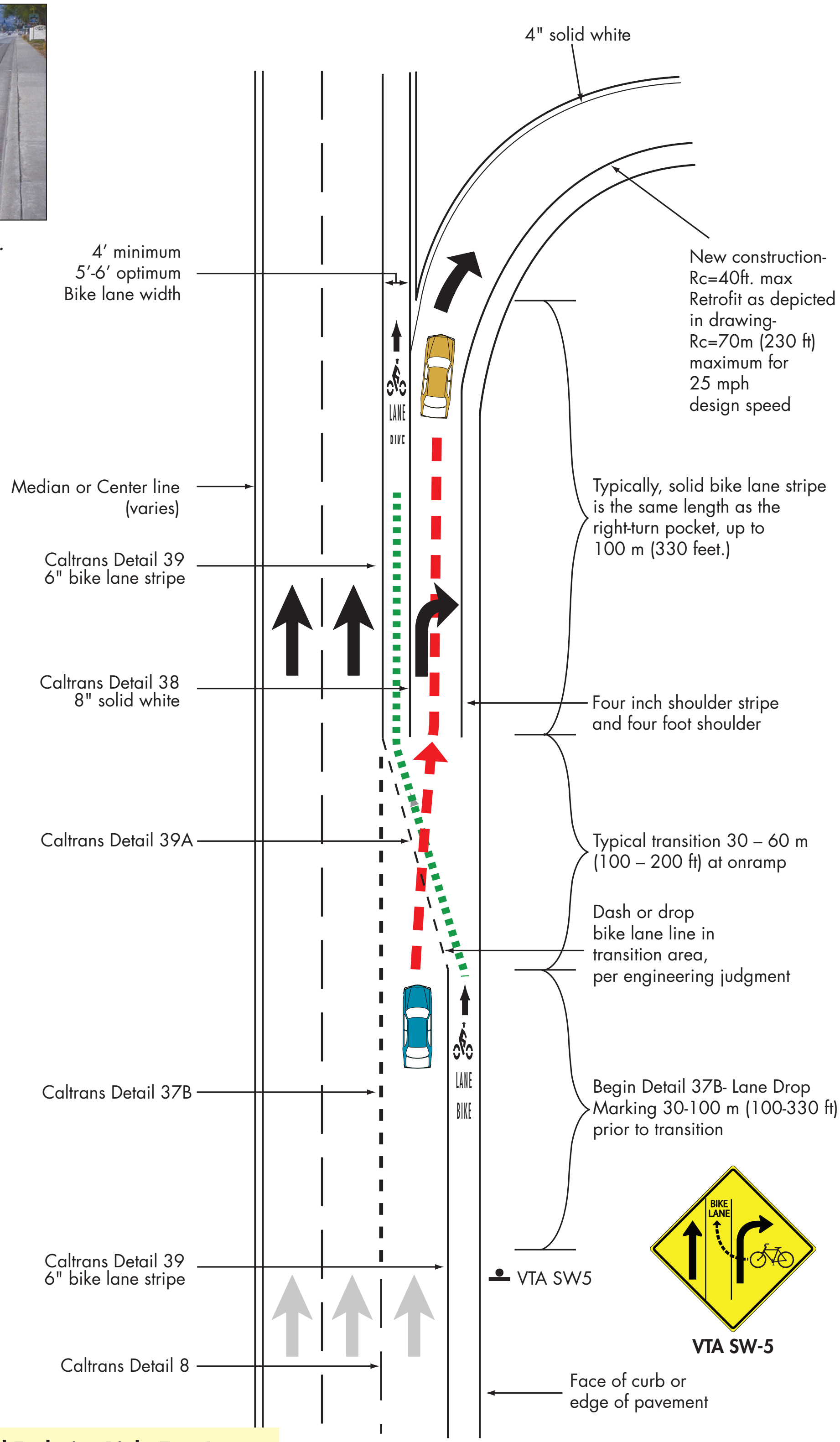
Figure 5-13:
Freeway On-ramp with Bike Lane and Exclusive Right-Turn Lane: Added Right-Turn Lane (Typically Unsignalized)

Not to scale

Cupertino: Stevens Creek Blvd. westbound approaching S.R. 85 northbound onramp

VTA Best Practice

This treatment is suggested as an interim measure until funding becomes available to retrofit the ramp geometry to be more bicycle and pedestrian friendly as shown in Figures 5-6, 5-12, 5-15 and 5-16.



Notes

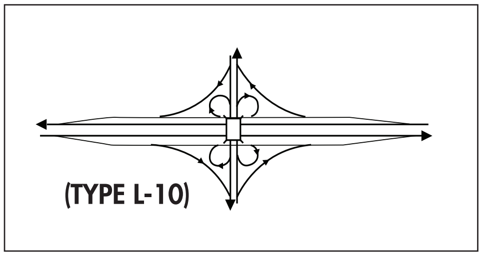
1. Posted speed 35 mph maximum.
2. Provide stopping sight distance for 10 mph more than the posted speed.
3. If interchange is a tight diamond or ramps are signal controlled, design the on-ramp's right-turn lanes per HDM Chapter 400.

Legend

- Typical travel path of bicyclist
- Typical travel path of right-turning motorist

Figure 5-14:
Freeway On-ramp with Bike Lane and Exclusive Right-Turn Lane: Trap Lane - Lane Drop (Typically Unsignalized)

Not to scale



5.3.3 Retrofitting Free flow Ramps and Cloverleaf Interchanges

Historically, a four-quadrant cloverleaf freeway interchange with a local road, i.e. HDM L-10, were built in rural or semi rural locations where real estate was plentiful, there was not much adjacent activity, and the local roadway was not expected to have much vehicular traffic let alone bicycles or pedestrians. These and other interchanges with “free-flow” style ramps enable all on- and off-ramp traffic to enter and leave the local roads at relatively high speeds and with no controls by traffic signals or STOP signs. However, in the intervening decades, nearby land uses have changed, and many of these interchanges are in areas where the resulting high speeds are no longer appropriate. In addition, the four-leaf clover design creates relatively short weaving sections between the loop ramps; when traffic volumes increase, the weaving area on the local road (and the freeway) becomes congested and there are increased conflicts for all roadway users. This is especially problematic for bicyclists traversing the interchange. See next section, 5.3.4, for a discussion of the situation with an auxiliary lane on the local street where the weaving, merging and diverging takes place.

The free flow ramps are compounded when they terminate as a free right-turn lane; see discussion in Section 5.3.5.

Redesigning and reconstructing an interchange to eliminate the free flow ramps is an expensive solution, but is slowly being implemented at the most congested locations in Santa Clara County such as Hwy. 101/Tully Road and Hwy. 101/Capitol Expressway in San Jose and elsewhere in the state.

In the interim, many communities are trying to develop lower cost solutions to improve pedestrian and bicycle safety. Short of reconstructing the entire interchange, options include:

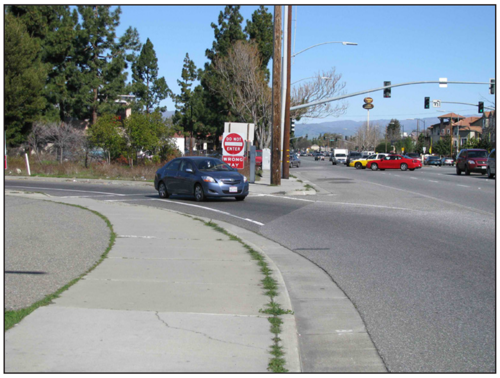
- Eliminate the loop onramp and construct left-turn lanes to accommodate the movement as illustrated in Figure 5-15. This may be feasible where the heavy traffic demand is to and from only one side of the freeway, such as occurs along I-280 in Los Altos Hills and Palo Alto.
- Eliminate the channelizing “pork chop” island and bring the ramp termini under signal control as shown in Figure 5-16.
- Provide a bike path within the median so that those who choose to can avoid the ramp conflict points, such as on El Monte Road at I-280 in Los Altos Hills. See Section 9.5 for discussion of median bike paths.

LOCAL TIP

The Santa Clara County, the City of Palo Alto, the Town of Los Altos Hills and Caltrans are cooperating on a feasibility study to evaluate options for the redesign of the I-280/Page Mill Road interchange.

High speed ramps are intimidating to many cyclists; this cyclist chose to ride on the sidewalk, but still must interact with a car entering the on-ramp.

At the I-280/El Monte Road interchange in Los Altos Hills, one cyclist rides on the median path while another chooses to ride in the roadway, illustrating that different cyclists have different preferences for navigating conflict points



Pork-chop island designs often allow motorists to turn without stopping at the signal.

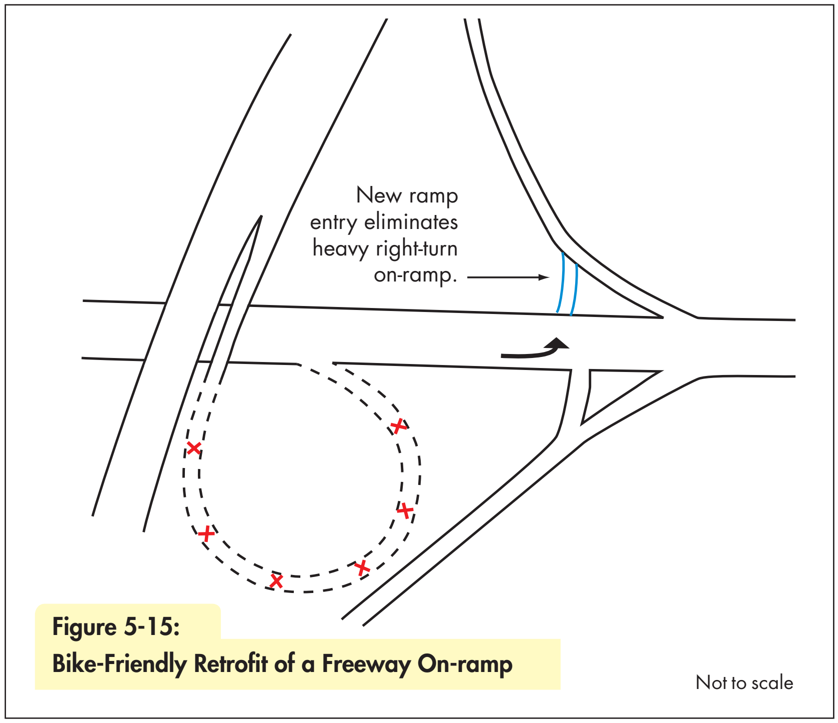


Figure 5-15:
Bike-Friendly Retrofit of a Freeway On-ramp

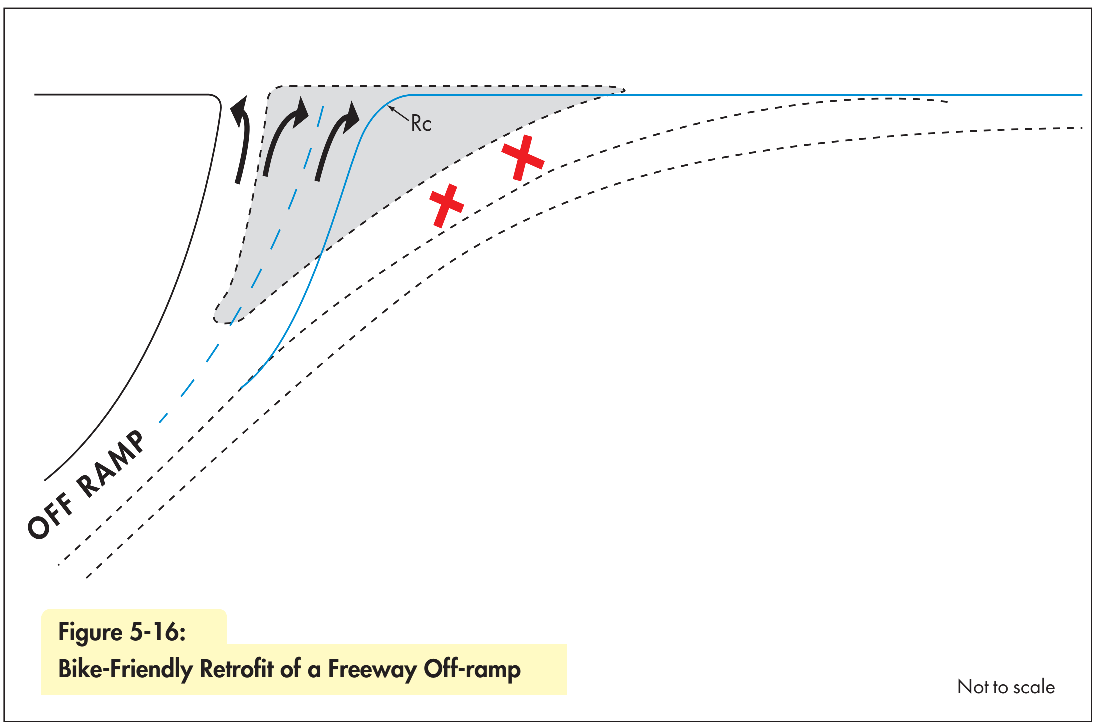


Figure 5-16:
Bike-Friendly Retrofit of a Freeway Off-ramp

5.3.4 Auxiliary Lanes and Bike Lanes on Arterials

A continuous auxiliary acceleration/deceleration lane on an arterial presents numerous weaving and merging movements between through bicyclists and motor vehicles. By placing the bike lane on the left side of this lane, bicyclists are removed from most of the weaving and merging conflicts. See Figure 5-17 for guidance.

This green bike lane on Stevens Creek Blvd. in the City of Santa Clara is to the left of the auxiliary lane.

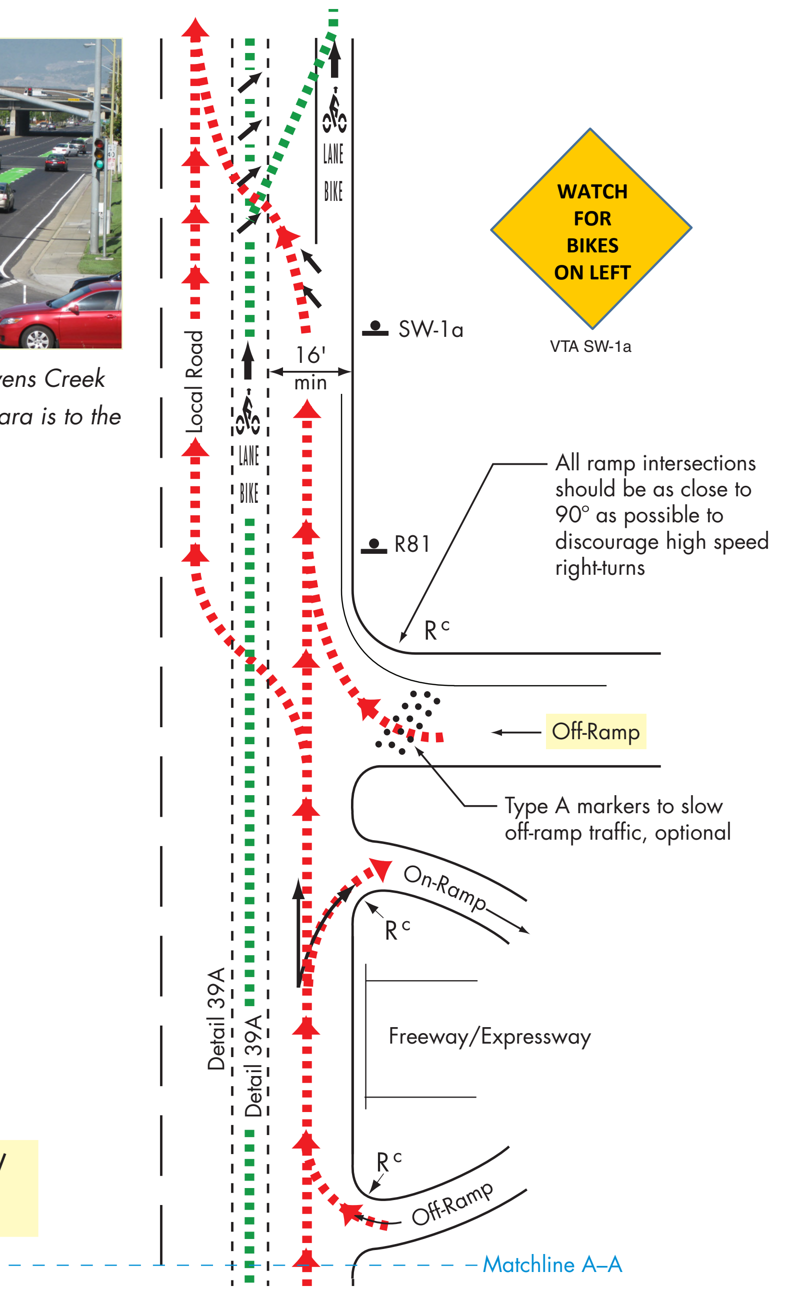
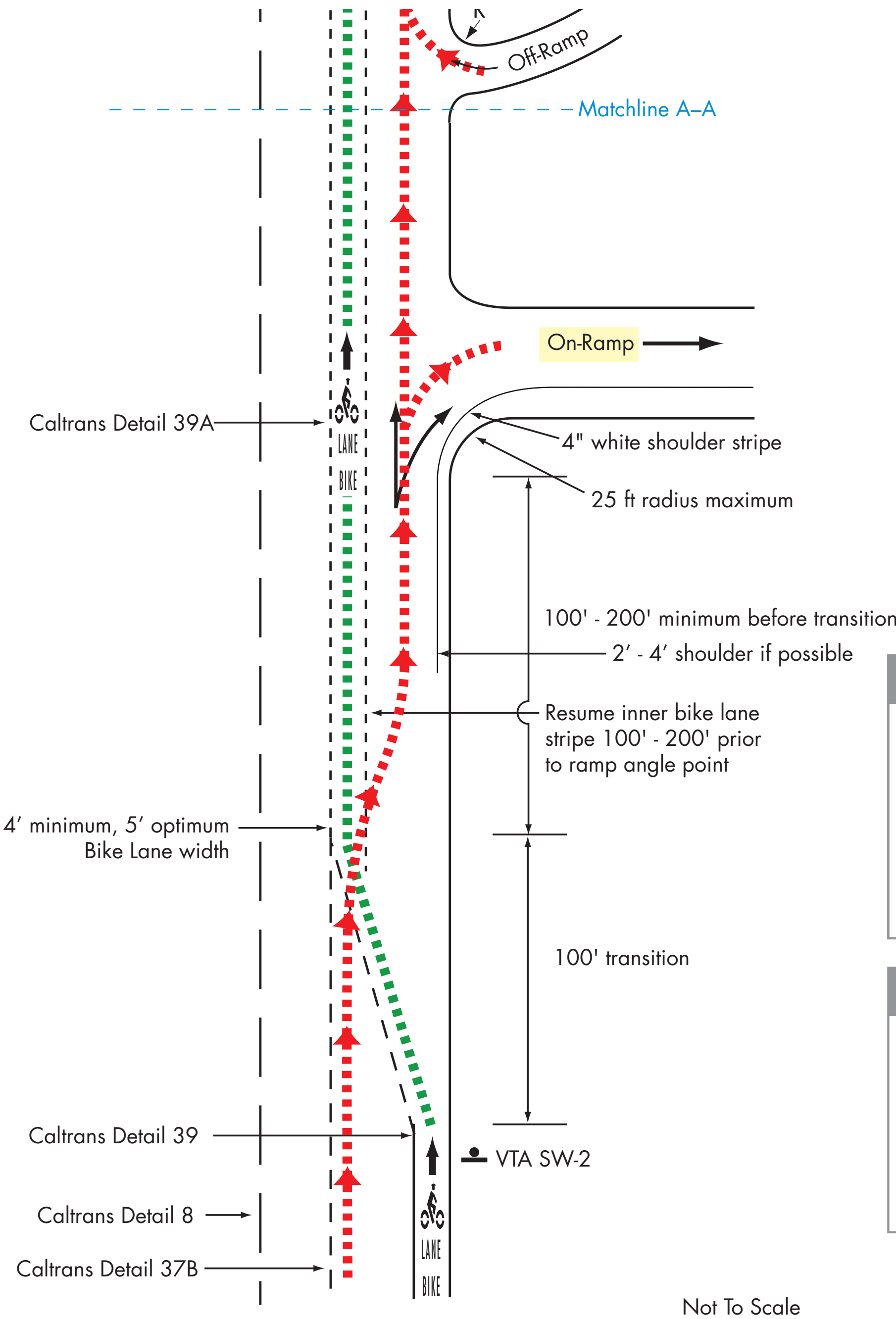


Figure 5-17: Arterial with Acceleration/ Deceleration Lane

Not to scale

Continue on page 5-23



ADVANCE OF
ON-RAMP
VTA SW-2

Notes

1. Posted speed 35 mph maximum.
2. Provide stopping sight distance for 10 mph more than the posted speed.
3. If interchange is a tight diamond or ramps are signal controlled, design the on-ramp's right-turn lanes per HDM Chapter 400.

Legend

- Typical travel path of bicyclist
- Typical travel path of right-turning motorist
- R^c Curb radius at ramp terminus = 40′ max, 25′ optimum

Figure 5-17 continued from page 5-22

Not to scale

Free right-turn lanes at freeway off-ramps can be more problematic than at other locations due to the higher speed of traffic coming from the freeway.

5.3.5 Free Right-Turn Lanes

Caltrans Standard

HDM§ 504.3(3) *Location and Design of Ramp Intersections on the Crossroad* states:

Where a separate right-turn lane is provided [on the ramp] at ramp terminals, the turn lane should not continue as a "free" right. It is preferred that the turn lane be controlled by a signal, "STOP" or "YIELD" sign. Free rights are problematic for pedestrians, bicycle traffic and vehicular merges.

VTA Best Practice

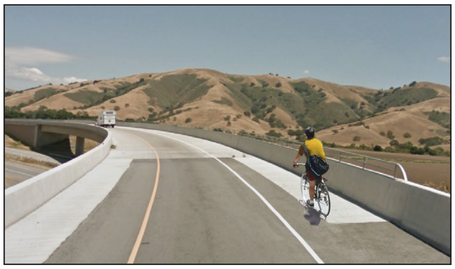
Free right-turn lanes are not to be provided in new construction. Ideally, existing free right-turn lanes would be completely removed. In the interim, Figure 5-7 in Section 5.1.3 presents options for modifying an existing free right-turn lane to be safer for bicyclists and pedestrians.

LOCAL PRACTICE

The Santa Clara County Roads and Airports Department is installing a bicycle-actuated flashing yellow beacon (FYB) at Central Expressway and Fair Oaks Blvd. to alert drivers on the expressway of merging bicyclists, and will be evaluating its effectiveness.

A through bicyclist will find himself in between two lanes of fast moving traffic at this location with a free right-turn lane.

The new grade- separated overpass of eastbound SR 152 at SR 156.



Eastbound SR 152 flyover of SR 156 has wide right-hand shoulder with bicycle railing to accommodate the bicyclists on this route.

5.4 Highway Grade-Separated Interchanges

When two arterials and/or state highways have capacity constraints, a solution used has been to grade separate the conflicting movements, e.g. the existing De La Cruz Blvd. crossings of El Camino Real and Coleman Avenue and the new design for SR 152/SR 156. This solution can pose circulation difficulties for bicyclists due to:

- Grade of overpass/flyover
- High design speed and travel speed
- Lack of shoulders or bike lanes on overpass
- Unsafe weaves and merges in order to traverse through the interchange (see Detail A and Detail B)
- Design that results in bicyclists having to be in uncomfortable and/or illogical lanes forcing a merge across a full lane of high speed traffic (see Detail C)

The design should ensure that bicyclists continuing on a shoulder will not end up in an unusual or an atypical place for a bicyclist. The solution for the SR 152/SR 156 interchange is illustrated in Figure 5-18.

Design elements of such a project should include:

- Maximum design speed of 35 mph
- Maximum grade of 5%
- 8 ft shoulders or bike lanes throughout
- Bike Path "by pass"

Bikes exit the shoulder of northbound SR156 onto bike path in order to avoid situation illustrated in Detail C (next page).

Legend

▪▪▪▪▪▪▪	Typical travel path of bicyclist on existing wide shoulder
━━━	Bicycle travel path on Bicycle Path Bypass
✕ ✕ ✕ ✕	Travel path of bicyclists who do not use the Bicycle Path Bypass
▬ ▬	Travel path of motorist

Notes for Figure 5-18

1. At the gore, ensure that the gore is paved at least to the 20′ width point in order to provide for bicycle refuge and stacking. See Detail A and Detail B.
2. A refuge area for bicyclists should be provided to the right of the right shoulder prior to the gore of the exit ramp. The bicyclists can then merge to a gore area which is paved at least to the 20′ width point and then merge. See Detail A.
3. Specific bicycle signs may be installed to direct bicyclists to the proposed refuge areas and to indicate crossing areas.
4. Provide a Bicycle Path Bypass at grade level so that bicyclists can avoid the weave on far side of the merge. Signs indicating the Begin and End of the bike path shall be installed.
5. The railing on the overpass must be 48 inches minimum height to meet HDM standards for bicycle traffic; see Chapter 9.

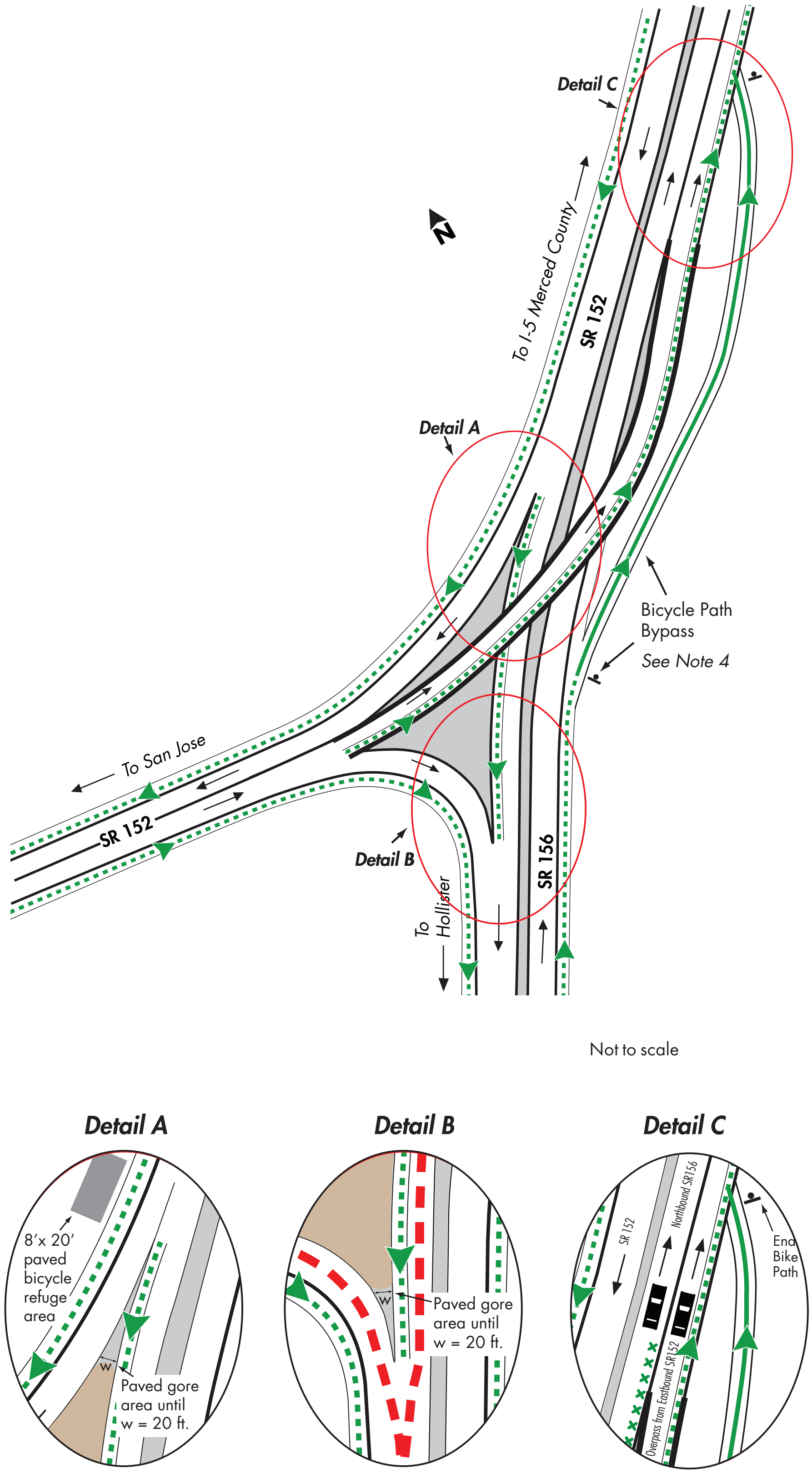


Figure 5-18: Grade-Separated Intersection of Two Highways – Bicycles Permitted

6 SIGNALIZED INTERSECTIONS

6.1 TRAFFIC SIGNAL TIMING

Signal timing affects bicyclists in four ways: (1) the minimum green times, (2) clearance intervals, (3) progression, and (4) visibility of signal heads.

6.1.1 Minimum Green Time

The minimum green time at all traffic signals should be calculated so that cyclists can fully clear an intersection after lawfully entering from a stopped condition. The minimum green time is especially important for cyclists crossing a major street from a minor street due to the extra crossing distance posed by six and eight-lane arterials; this minimum green interval, where a minor street intersects a major arterial, is often reduced to a minimum value of 4 to 6 seconds, which is typically insufficient for cyclists to clear the intersection. Generally eight seconds is sufficient except for wide arterials. Specific guidance for calculating minimum green times is presented below. An example signal timing calculation is presented on page 6-4.

The minimum green time depends on the cross street width, slope of the approach, and the bicyclist's ability. The important value is the total length of the signal phase, i.e. minimum initial green plus yellow plus red clearance. The value of $g + y + r_{clear}$ must exceed the time t_{cross} needed for bicyclists to cross the intersection plus time t_{loss} the start up time lost, as represented in the formula below:

$$g + y + r_{clear} \geq t_{cross} + t_{lost}$$

Caltrain Guidance

$$g + y + r_{clear} \geq \frac{(w + 6 \text{ ft.})}{14.7 \text{ ft./sec.}} + 6 \text{ seconds}$$

Once the value ($t_{cross} + t_{lost}$) is calculated, then the minimum green time is determined by subtracting the actual values for the yellow and red clearance intervals.

Table 6 -1 Representative Bicyclist Speeds

Bicyclist Population	Average Speed	15th Percentile Speed	2nd Percentile Speed
Fast or commuter	18 mi/h (26 ft/sec)	14 mi/h (21 ft/sec)	12 mi/h (18 ft/sec)
Casual adult	12 mi/h (18 ft/sec)	10 mi/h (14 ft/sec)	8 mi/h (12 ft/sec)
Children	9 mi/h (13 ft/sec)	7 mi/h (11 ft/sec)	6 mi/h (9 ft/sec)

NOTE

Sections 6.1 and 6.2 are a summary of MUTCD-CA § 4D.105 and the ITE Journal article Signal Clearance Timing for Bicyclists, Wachtel, Forester and Pelz, March 1995.

TECH TIP

t_{cross} = (w + l)/v where w = intersection width, l = length of the bicycle and v = bicyclist speed.

t_{loss} = the start-up time lost by the bicyclist reacting to the green light and accelerating to full speed, and is typically 6 seconds.

NOTE

Note that the formula from MUTCD CA § 4D.105 uses 14.7 ft./sec. to represent the final crossing speed of the cyclist. T o choose a different value for cyclist speed for site-specific conditions, refer to Table 6-1.

Design Considerations

The most likely victims of clearance-time accidents are the large number of bicyclists waiting at a red light who start up on a new green. The minimum green time should be sufficient for a bicyclist starting from a dead stop to mount the bicycle, start pedaling and to be more than halfway through the intersection before the light turns yellow. Standard clearance intervals are usually sufficient to enable bicyclists to finish crossing the last half of the intersection. Signalized intersections on routes to school should take into account the slower reaction and riding times of students and the likely larger groups of bicyclists near schools.

The effect of a longer green time on traffic flow on the major street is normally slight. At peak hours, the side streets are typically full and trigger a long signal phase regardless of the presence of bicyclists; at non-peak times the major street does not need its full capacity and can tolerate longer delays (the signal cycle is undersaturated). If necessary, the major street's green interval can also be lengthened to preserve its proportion of the signal cycle.

6.1.2 Clearance Intervals

Bicycle clearance-time conflicts occur when a bicyclist traveling on a minor street, which carries slow and infrequent traffic and has a short signal phase, crosses a wide major street that carries high-speed traffic. Clearance timing is even more important for bicyclists than for motorists, because bicyclists move more slowly, are more easily hidden from view, and are more vulnerable to injury.

The following guidelines should be used to determine yellow, red, and green intervals at traffic signals where bicycles are permitted. They can provide the greatest benefit where one or more of the following is true:

- Bicycle clearance-time accidents have already occurred.
- Physical characteristics (such as width) and bicyclist volume make these accidents likely.
- A bike-laned street or a signed bicycle route crosses a major street.

Guidance for calculating clearance intervals is presented below. The approach speed v to be used in the formula is presented in the previous Table 6-1.

Design Considerations

Yellow Clearance Interval

The clearance interval (yellow plus all-red) should be sufficient for a bicyclist who reaches the intersection when the light turns yellow to proceed through the intersection. The standard yellow interval y for motor vehicles is given by:

$$y \geq t_r + v/2b$$

where t_r is reaction time, v is approach speed, and b is the magnitude of the vehicle's braking deceleration. The fastest bicyclists normally travel no faster than motor vehicles, and the braking deceleration of the two types of vehicles is comparable. Slower, less experienced bicyclists can be expected to brake less effectively, but they also travel at slower speeds. Under normal circumstances, therefore, yellow intervals calculated for motorists do not need to be adjusted for bicyclists.

This cyclist may not be able to stop when the light turned yellow and needs the clearance interval to cross to the far side of the intersection.

Longer yellow intervals do not help to prevent clearance-time accidents, because some bicyclists will always enter (lawfully) on the last of the yellow. A better solution is to provide an all-red clearance interval, during which the intersection can clear safely before cross traffic is allowed to enter.

Red Clearance Interval

Very long red clearance intervals are not commonly used, because they reduce the efficiency of the intersection, and may encourage motorists to enter on red. The MUTCD-CA, for instance, generally limits red clearance intervals to 2.0 seconds. A red clearance interval of at least this length is preferable to minimize the risk for bicyclists who are caught in the intersection.

For maximum safety, the red clearance interval should last long enough for a bicyclist who enters late in the green or during the yellow interval to cross the intersection at full speed:

$$r_{clear} \geq (w + l)/v$$

where w is the width of the intersection, measured from the near-side stop line to the far edge of the conflicting traffic lane, l is the length of the bicycle (typically 6 ft), and v is the average speed of bicyclists.

Signal Timing Example

This section shows an example of a signal timing calculation. The two values needed are:

- *Intersection width (measured from the near-side stop line to the far edge of the farthest traffic lane);*
- *Speed of the slowest bicyclist to be accommodated.*

This speed depends on the average speed of bicyclists using the intersection, the distribution of speeds around that average, and the cutoff point that the traffic engineer chooses. These speeds are best determined by direct local observations; if no observations are available, the speeds in Table 3 can be used.

For this example, consider an intersection 120 ft wide, used primarily by casual adult cyclists. In this group, 98 percent speed of cyclists travel at 12 ft/sec or faster, so this is chosen as the design speed.

Yellow Interval

First, decide on the yellow interval for vehicular traffic. This value will also be acceptable for bicyclists. For instance, for an intersection with an approach speed of 35 mi/h or less, the MUTCD-CA recommends a yellow interval of 3.0 sec.

Red Interval

Next, calculate the red clearance interval. Ideally, this interval would be long enough for a bicyclist entering on the very last of the yellow to cross the entire intersection (plus 6 ft more for the length of the bicycle):

$$(120 \text{ ft} + 6\text{ft})/(12 \text{ ft/sec}) = 10.5 \text{ sec}$$

Red clearance intervals this long are not commonly used, because they reduce the efficiency of the intersection, and may encourage motorists to enter on red. MUTCD-CA recommends red clearance intervals up to 2.0 sec. For this reason, the traffic engineer in this example chooses a red clearance interval of 2.0 sec. (Longer red clearance intervals may be justified at very wide intersections.)

Total Crossing Time

The next value to calculate is the total crossing time for bicyclists starting on a new green. This time is longer than the 10.5 sec calculated under "Red Interval" above, because these bicyclists need time to react to the green light and to accelerate to full speed. Again, direct local observations are best; otherwise, as a rule of thumb, use 6 sec for this startup time. This makes the total crossing time for the slowest bicyclists starting on a new green:

$$10.5 \text{ sec} + 6 \text{ sec} = 16.5 \text{ sec}$$

Minimum Green

Finally, minimum green is just the total crossing time minus the red and yellow intervals already found:

$$16.5 \text{ sec} - 3.0 \text{ sec} -2.0 \text{ sec} = 11.5 \text{ sec}$$

Note that a longer red clearance interval would enable the use of a shorter minimum green.

The timing at this signal would then be:

minimum green............. 11.5 sec

yellow.............................3.0 sec

red clearance ....2.0 sec

Reducing the Minimum Green

It is possible to reduce the minimum green time slightly by allowing only the front of the front wheel of the bicycle, rather than the rear of the rear wheel, to clear the intersection, and by measuring to the center of the far lane rather than to its farthest edge. The first change reduces the effective intersection width in this example from 126 ft to 120 ft, and the second from 120 ft to 114 ft (half a lane width), or 12 ft altogether. This reduces the total crossing time and minimum green time by:

$$(12 \text{ ft})/(12 \text{ ft/sec}) = 1 \text{ sec}$$

The minimum green time then becomes 10.5 sec instead of 11.5 sec. Yellow and red intervals are unchanged.

6.1.3 Progression

VTA Best Practice

Optimally, in areas such as commercial districts and Central Business Districts (CBD's), signals should be timed for bicycle speeds approximately 12 to 15 miles per hour. The high pedestrian activity typically found in these areas would also benefit from the slower speeds. This strategy is typically employed in areas such as CBD's where every block is signalized. Time-space diagrams should be checked for bicycle speed compatibility (12-15 mph) and adjusted if feasible.

NOTE

The timing of traffic signals so that they turn green as the bicycle or vehicle approaches is often called a "green wave".

Design Considerations

Signals along an arterial are often timed to maximize automobile throughput. Although this has positive benefits for fuel savings and auto-travel time, unfortunately this often means that they are ill-timed for bicyclists. A signalized arterial could be coordinated for bicycle speeds rather than motor vehicle speeds as has been done in Portland, Oregon where downtown streets are timed at 14 mph.

TECH TIP

Lead Bicycle Intervals, just like Lead Pedestrian Intervals, can help reduce conflicts with right-turning vehicles by giving the cyclists a head start before the motorist receives the green indication.

6.1.4 Visibility of Signal Heads

VTA Best Practice

Programmed visibility signal heads shall be positioned such that they are visible at the right-hand side of the right-most through lane or the bike lane where a bicyclist would be expected to travel. They shall also be positioned to be visible from the right-hand side of the right-most left-turn lane.

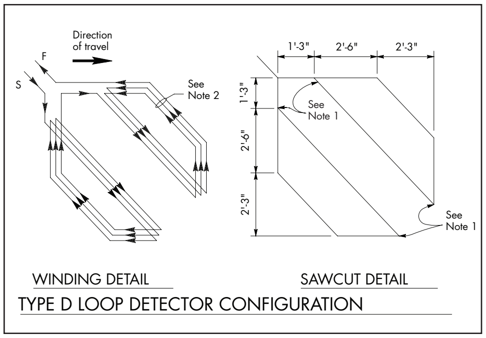
6.2 TRAFFIC SIGNAL DETECTION

At actuated signals, the detection technology must be able to detect a bicycle. It is particularly imperative at intersections with major street recall, i.e. where minor streets only receive the green signal upon the detection of a vehicle. Bicycle detection is also important at left-turn lanes with protected left-turn phasing. Without bicycle detection, the bicyclist is forced to do one of the following: wait for a motor vehicle to arrive and trigger the light; dismount to push the pedestrian button (if there is one) or proceed on a red light.

If cyclists are not detected by traffic detectors, they are subjected to undue delay from either waiting for a motorist to arrive, if at all, or having to dismount to find a pedestrian push button, if any. At times, cyclists are even forced to proceed during a gap in traffic.

Caltrans Standard

New or modified detector installations must detect bicycles on all approaches and movements or be placed on permanent recall or fixed time operation. See MUTCD-CA § 4D.105. Also refer to CVC § 21450.5.



Source: Caltrans SP ES-5B

This Type Q detector in the bike lane means that the bicyclist will trip the signal without deviating from the normal travel path.

If existing signals are being retrofitted to detect bicycles, priority should be given to those approaches without recall, i.e. minor streets, and left-turn lanes. At T-intersections, the bike-sensitive detector should be placed in the left-turn lane of the bottom of the tee, since the right turning bicyclists can turn on a red light.

The following presents the guidelines for various technologies of bicycle detection:

6.2.1 Inductive Loop Detection

Inductive loops are the most common type of vehicle detection; they can be adjusted to detect bicycles as well.

Detectors that meet the specifications of the Reno A&E detection module can detect bicycles at the low sensitivity setting (which reduces false calls).

The optimum use and placement of the various types of inductive loop detectors are:

a) Through lanes shared with bicycles: Type D-modified quadropole loops.

b) Left-turn lanes/minor side streets: State Type 5DA loop.

c) Bike lanes: Type Q-quadropole loops.

d) Advance detectors in the curbside lane should also detect bicycles-Type D.

e) Advance detectors that are not expected to be shared by bicycles can be Type A.

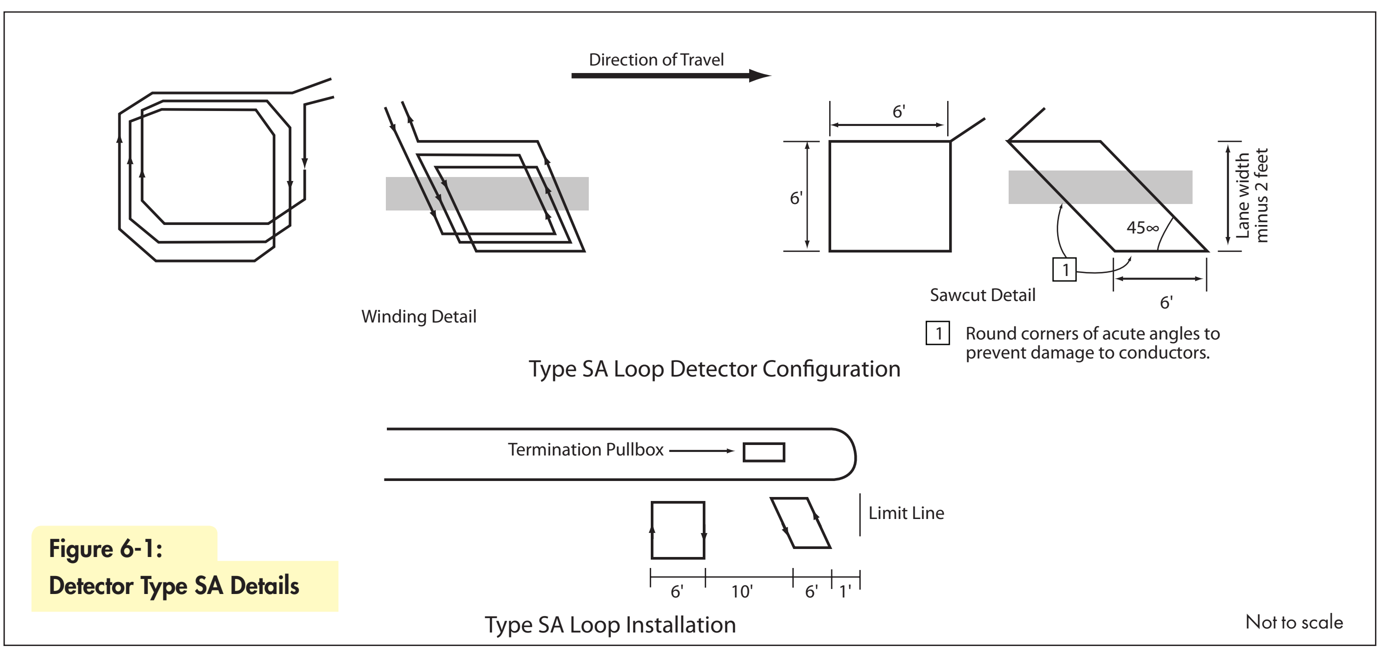
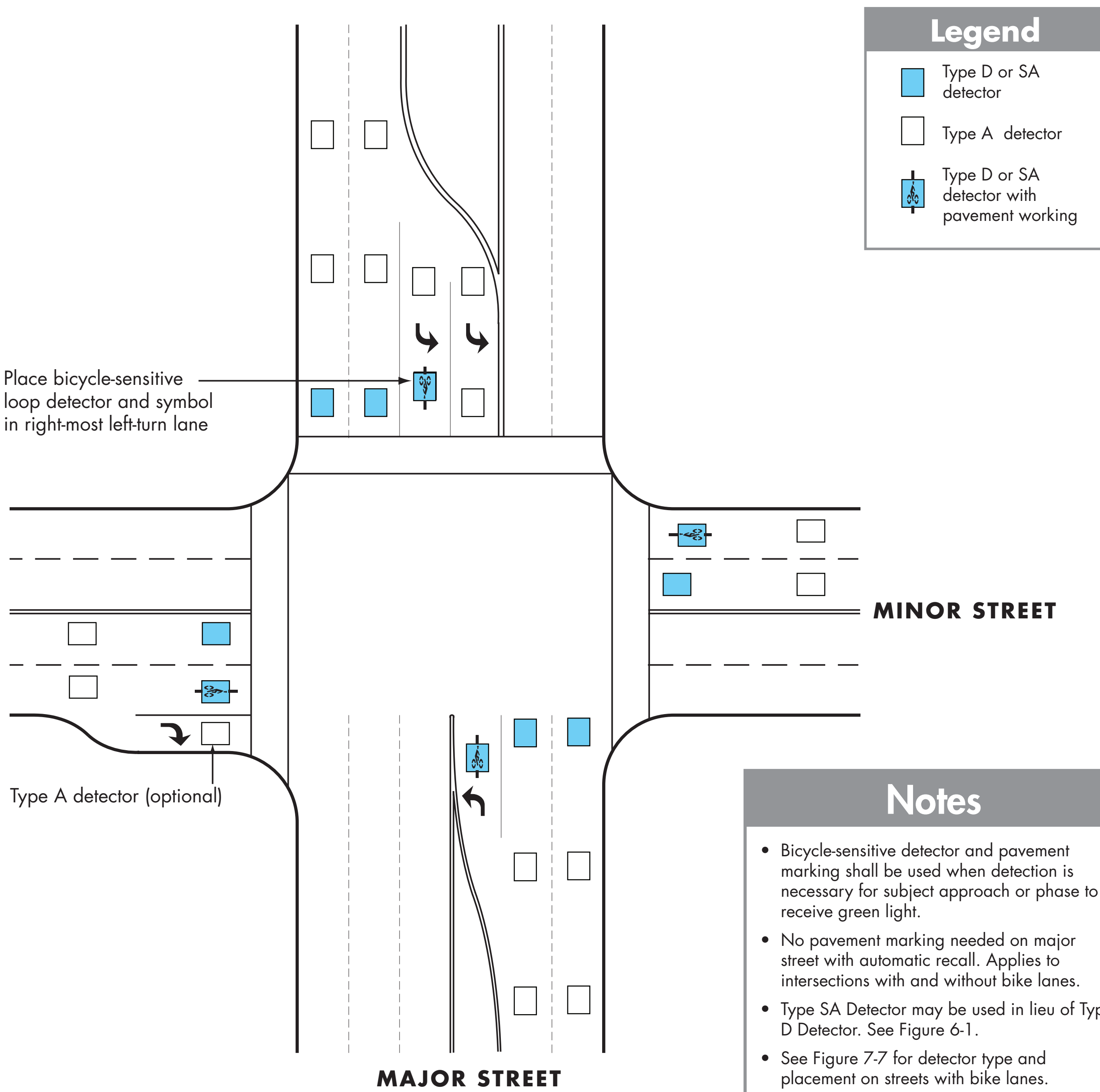


Figure 6-1: Detector Type SA Details

Figure 6-1 (left) illustrates Detector Type SA used by the City of Cupertino and Figure 6-2 (below) illustrates the typical detector placement at a five-phase signalized intersection.



Notes

- Bicycle-sensitive detector and pavement marking shall be used when detection is necessary for subject approach or phase to receive green light.
- No pavement marking needed on major street with automatic recall. Applies to intersections with and without bike lanes.
- Type SA Detector may be used in lieu of Type D Detector. See Figure 6-1.
- See Figure 7-7 for detector type and placement on streets with bike lanes.
- "Optimum": The best or most favorable condition from the perspective of responsible management.
- Reference also: Highway Design Manual, Chapter 1000 Bikeway Planning and Design and the Traffic Manual.

Figure 6-2:
Detector Layout at Five-Phase Signalized Intersection

Not to scale

With no traffic to trip the detector, this loop detector pavement marking tells the bicyclist where to wait.

R10-22

A bicycle signal head in Davis, California.

6.2.2 Pavement Markings for Detector Locations

The location of the most bicycle-sensitive portion of the loop detector should be indicated by the standard loop detector pavement marking (Standard Plans A24C) as is standard practice in Cupertino, Santa Clara and Sunnyvale.

The R10-22 sign indicates the meaning of the pavement marking; typically this sign would not be needed at every installation; only for example where significant volumes of new or young bicyclists are present.

6.2.3 Alternative Detection Technologies

Three other detection technologies show promise at detecting all bicycles regardless of their metal content: Video Detection, Microwave Detection and Self-Powered Vehicle Detector (SPVD). These guidelines do not preclude projects from including these technologies as long as they reliably detect bicycles.

Video detection appears to be easier to maintain than loops since the adjustment to avoid false calls is less sensitive. The area of detection, however, needs to include the area where bicyclists typically wait. There may still be need for pavement markings to tell bicyclists where to wait to be detected. This technology is currently being used at a few intersections in Palo Alto.

Microwave detection has proven reliable in certain contexts including trails. Midian Electronics, Inc., in Tucson, Arizona, makes a product called the Self-Powered Vehicle Detector (SPVD) which detects bicycles as well as automobiles. One if its main advantages is that it is much easier to install than loop detectors (it requires only a 6-inch hole to be drilled in the pavement). The SVPD measures changes to the Earth's natural magnetic field when a vehicle approaches the detector. Recommended applications include intersections, bike paths, park entrances, and train detection.

6.3 BICYCLE SIGNAL HEADS

Bicycle signal heads were approved for use in California in 1999 (CVC §21456.2 & 21456.3); they are described in MUTCD-CA Section 4D.104 (CA).

A typical application is where a bike path enters an intersection at the top of the Tee and essentially receives a "scramble" phase. The City of Davis received a request to experiment from the CTCDC and experienced a reduction in collisions at all study intersections. The warrants for bicycle signal heads are presented in MUTCD-CA Section 4C.102 (CA) and in Appendix D.