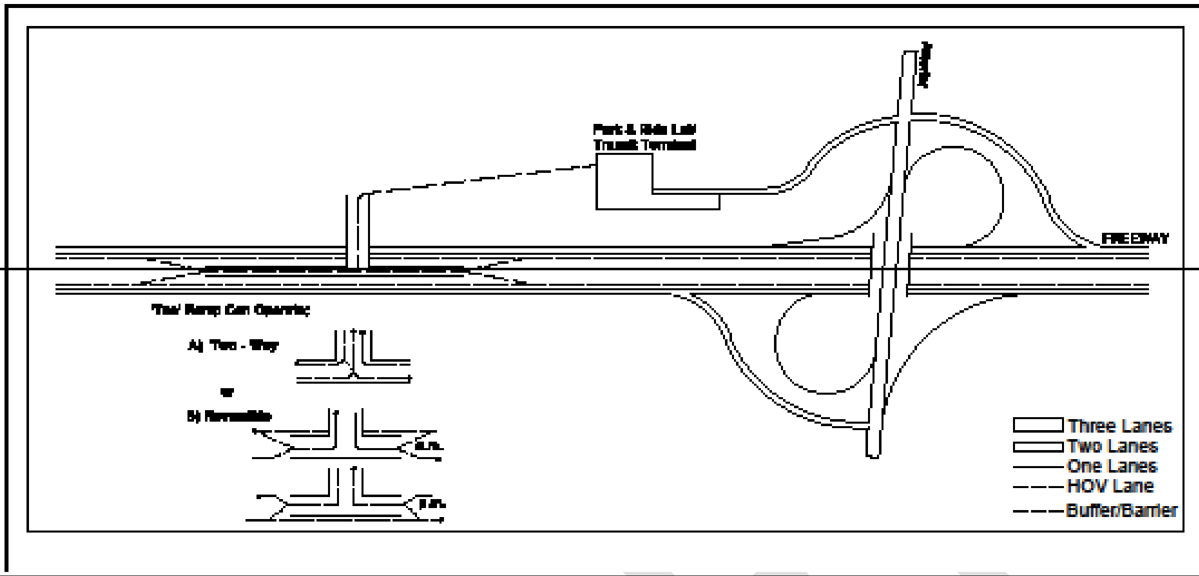
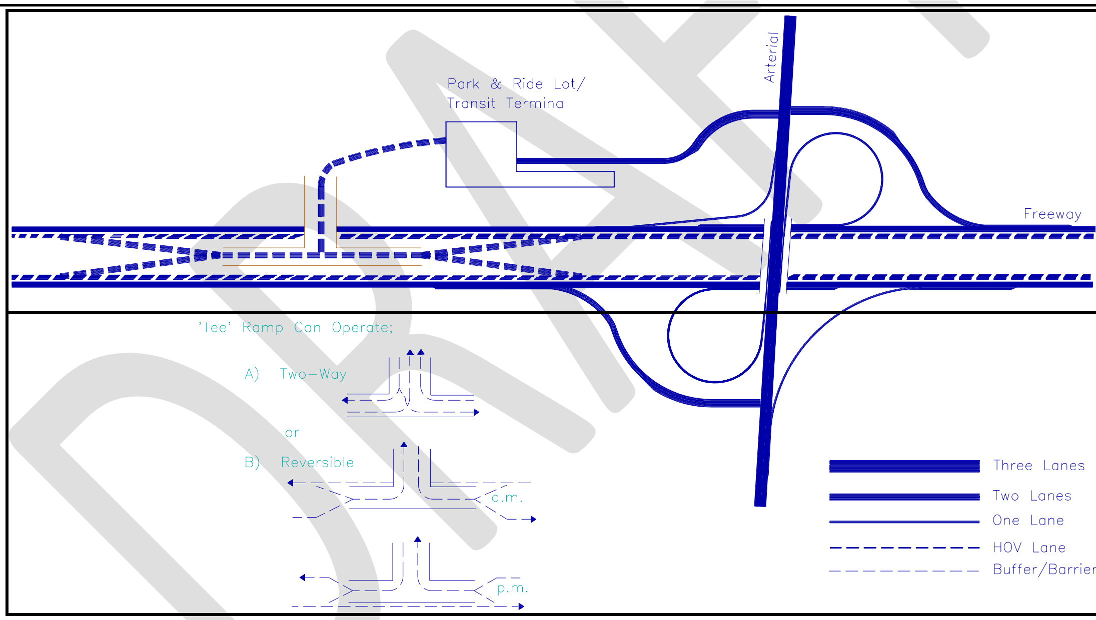
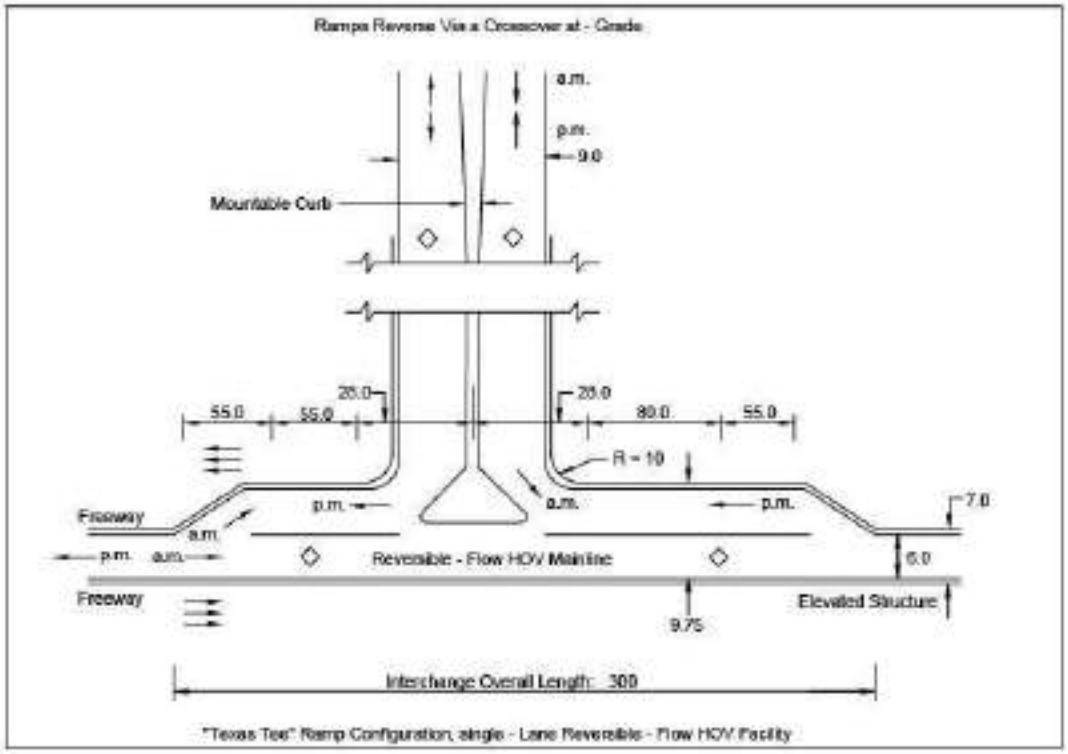


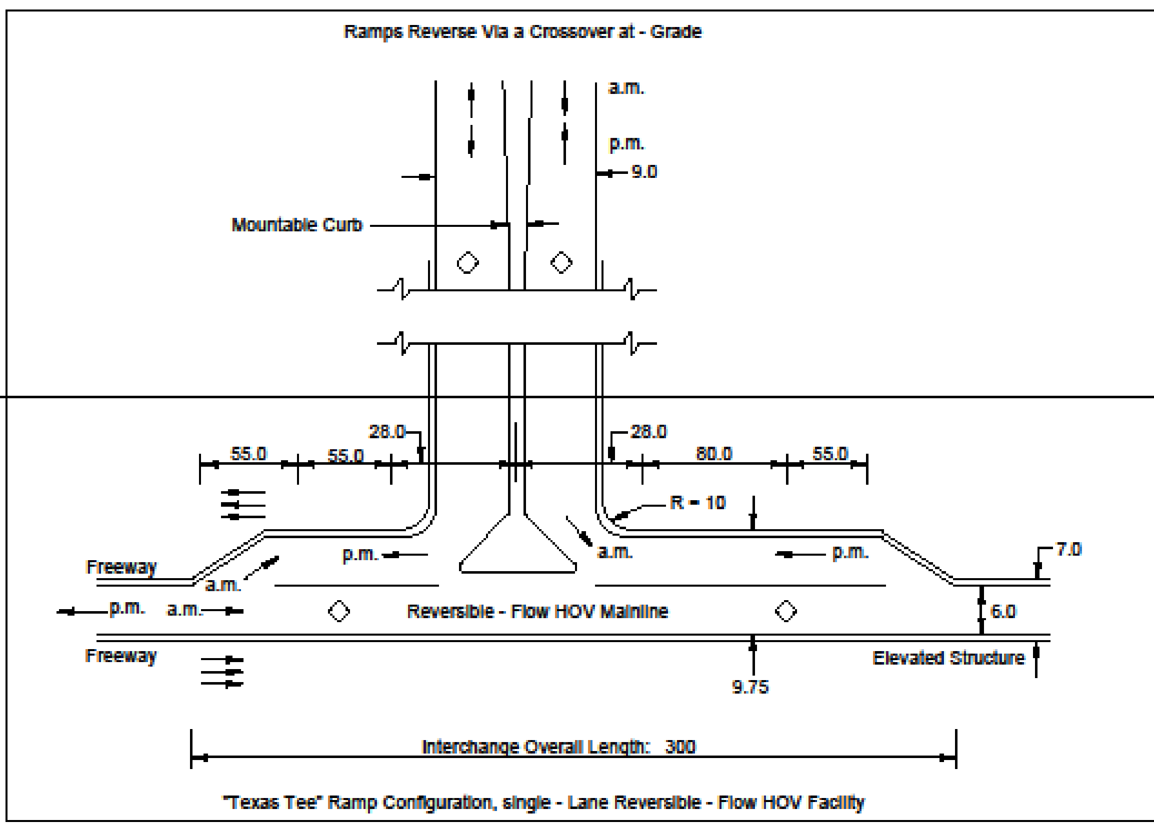


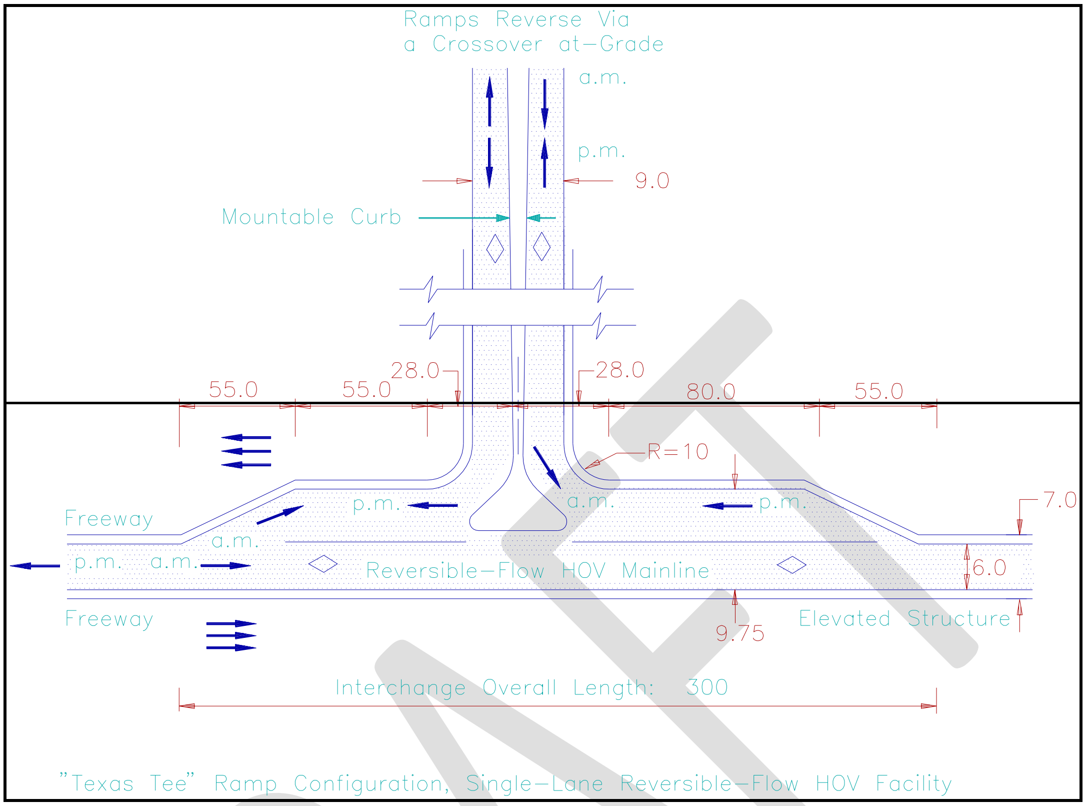
~~Figure 12.5.41 "Tee" Ramp for Direct Access Between Median HOV Lane and Off-Line Facility~~

Exhibit 12BK

Reversible Median "Tee" Ramp


Ramps Reverse Via a Crossover at - Grade
a.m.
p.m.
9.0
Mountable Curb
28.0
28.0
55.0
55.0
80.0
55.0
R = 10
Freeway
p.m.
a.m.
a.m.
p.m.
7.0
p.m.
a.m.
Reversible - Flow HOV Mainline
6.0
Freeway
Elevated Structure
9.75
Interchange Overall Length: 300
"Texas Tee" Ramp Configuration, single - Lane Reversible - Flow HOV Facility

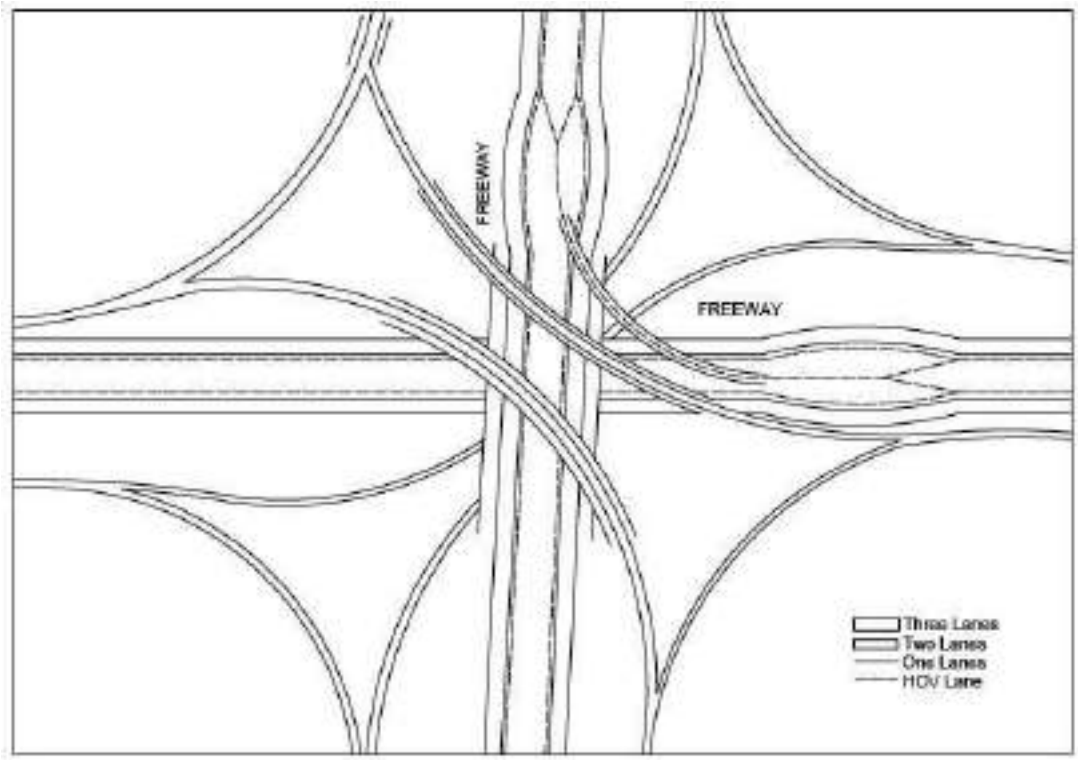

Ramps Reverse Via a Crossover at - Grade
a.m.
p.m.
9.0
Mountable Curb
28.0
28.0
55.0
55.0
80.0
55.0
R = 10
Freeway
p.m.
a.m.
a.m.
p.m.
7.0
p.m.
a.m.
Reversible - Flow HOV Mainline
6.0
Freeway
Elevated Structure
9.75
Interchange Overall Length: 300
"Texas Tee" Ramp Configuration, single - Lane Reversible - Flow HOV Facility

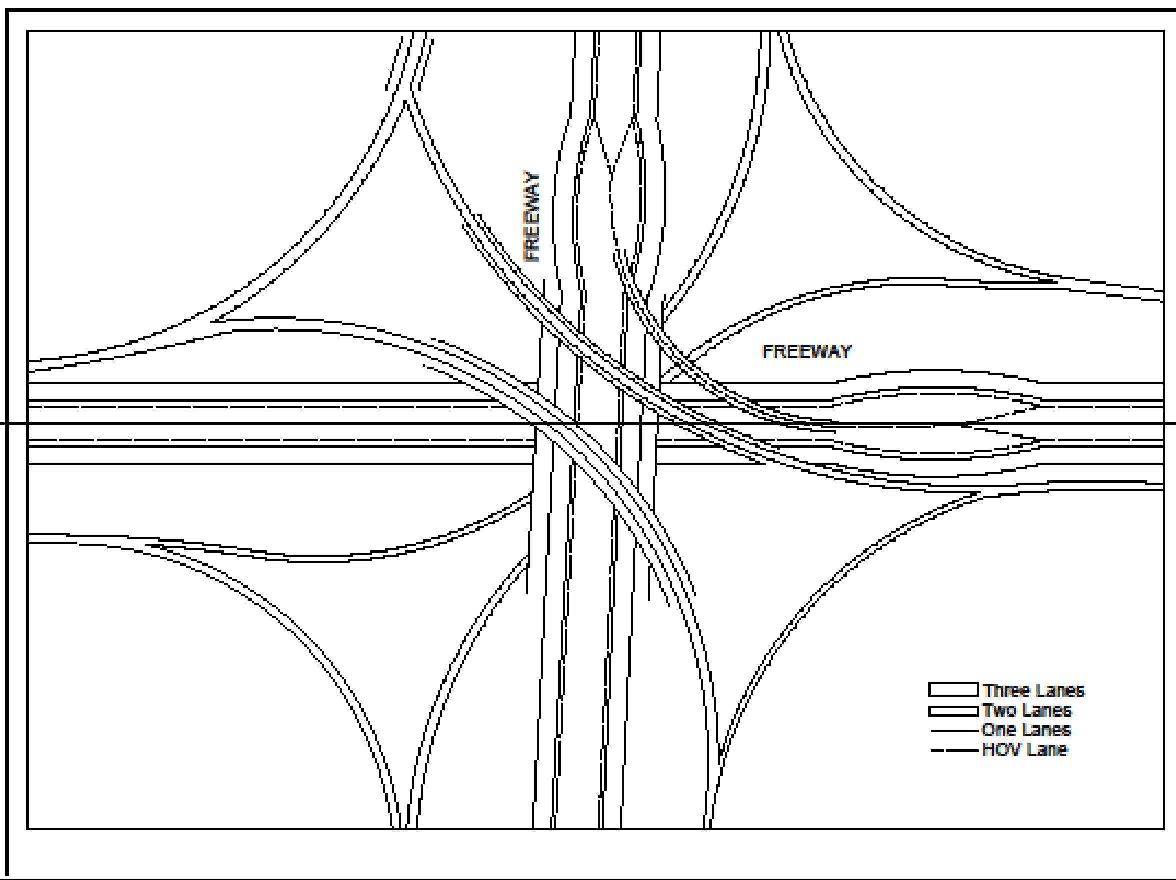


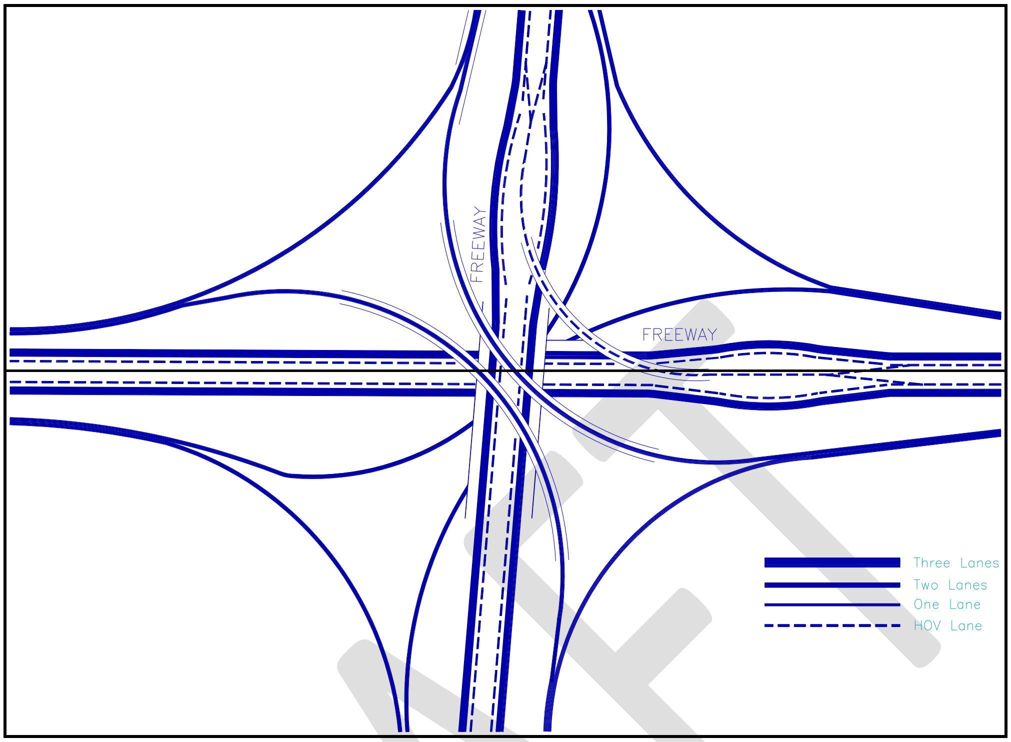
~~**Figure 12.5.42 Reversible Median "Tee" Ramp**~~

Exhibit 12BL

Freeway-to-Freeway Interchange with Direct HOV Lane Connection (Major Move Only)


FREEWAY
FREEWAY
Three Lanes
Two Lanes
One Lanes
HOV Lane


FREEWAY
FREEWAY
Three Lanes
Two Lanes
One Lanes
HOV Lane



~~**Figure 12.5.43 Freeway-to-Freeway Interchange with Direct HOV Lane Connection (Major Move Only)**~~

12.5.3 Bus Lane / Bus Only Lanes (BOL) Design

Within freeways, there are often opportunities to construct busways between the median barrier and the general-purpose traffic lanes.

The design speed of the median busway should match the design speed of the adjacent freeway to avoid differences in alignment geometry between the busway and the freeway. As a result, the geometry of the busway should meet geometric design guidelines.

The median busway should be designed with at least a 0.6 m (2 foot) paved shy distance between the edge of median barrier and edge of the bus lane. The bus lane should be at least 3.5 m (11.5 feet) wide, with a preferred width of 3.66 m (12 feet). The median busway does not require a horizontal separation between the bus lane and the adjacent general-purpose traffic lane, although 0.6 m of painted marking separation is desirable unless speed differential regulation applies in which case greater separation may be required.

The unobstructed vertical clearance over the busway should desirably be a minimum of 5.0 m (16.5 feet). The minimum recommended clearance is 4.7 m (15.5 feet). This will allow other vehicles, such as maintenance and emergency vehicles, to utilize the busway.

Lane designation signs should be installed at the start and end of the median busway. Overhead signs designating the busway should also be installed at intervals of about 15 seconds based on traveling at the posted speed. The maximum spacing of the signs should not exceed 30 seconds.

Pavement markings would consist of a solid white pavement marking between the bus lane and the general-purpose traffic lane and the words “Bus Only” painted in the busway cross-section, similar to HOV standard markings.

12.5.4 Part-Time Shoulder Use / Peak-Use Shoulder Lane

Part-time shoulder use or peak-use shoulder is the conversion of shoulders to travel lanes during some hours of day as a congestion relief strategy. This strategy is also known as temporary shoulder use or hard shoulder running or peak-use shoulder lane is typically implemented on freeways. This construction approach allows to add more space for travelers in a quicker and more cost-effective way than expanding highways. Drivers may use the designated shoulder in specific areas as an additional lane during times with heavy congestion. It is a transportation system management and operations strategy that uses shoulders to provide additional capacity when it is most needed or when general-purpose lanes are closed for construction or incidents. When an additional travel lane is not needed, the shoulder will be restored to its original purpose and the basic physical characteristics are retained.

There are no occupancy requirements for the vehicles to use the peak-use shoulder lane, and the speed limit is the same as the rest of the roadway.- However, Part-time shoulder may not be an appropriate strategy where minimum geometric clearances, visibility, and pavement requirements cannot be met, or it may have an adverse impact on safety.

In the event of an emergency or blocking vehicle during lane operations, the peak-use shoulder will be closed (in the case of the dynamic lanes, using the overhead lane control signs) until the problem is able to be cleared.

12.5.4.1 Design Elements of Part-Time Shoulder

Beginning and End Segments

Part-time shoulder use can begin and end along segments or at ramps. If the beginning or end of a static or dynamic shoulder use segment falls along a basic freeway segment, then it would desirably be located such that it is highly visible and easily comprehended to approaching drivers. Horizontal curves crest vertical curves, and overpasses may limit a driver’s visibility of a downstream roadway, and dropping any type of lane, including a shoulder open to part-time travel, within or immediately beyond these features should be avoided if possible. Likewise, dropping any type of lane in or immediately beyond an area with extensive, complex signing or other features contributing to high driver workload should be avoided, if possible. The desirable locations for lane drops are also desirable locations to begin shoulder use.

Part-time shoulder use on freeway segments should include pavement markings at the beginning of the area designated for shoulder use that guide drivers from the adjacent general-purpose lane onto the shoulder but also maintain continuity of the general-purpose lane. Shoulder use ends along freeway segments are designed like shoulder use adds. A solid edge line is typically used to transition traffic from the shoulder back to the adjacent general-purpose lane.- Carrying part-time shoulder use through system interchanges is more complex due to conflicts with exiting and entering traffic. At major forks, the shoulder lane can be carried onto one of the forks. This is desirable if the ramps downstream of the fork have more lanes than the freeway approaching the fork.

Lane Width

For shoulders designated for part-time travel, a width of 3.66 m (12 feet) or more is generally preferred. Narrower shoulders may be adequate depending upon the type of vehicles using the part-time shoulder lane, the available lateral offset to obstructions beyond the pavement edge, and if speed restrictions will be used when the shoulder is open. If trucks are prohibited from using the shoulder, then widths as narrow as 3.35 m (11 feet) may be adequate. Shoulders less than 3.35 m (11 feet) wide are not recommended for part-time shoulder use.

A 3.35 m (11 feet) shoulder may be inadequate for part-time shoulder use if the lateral offset to obstructions is less than 0.5 m (1.5 feet) or a high volume of larger vehicles such as buses is anticipated.- Opening the shoulder only when congestion is present and reducing the speed limit when the shoulder is open will likely improve the safety of a narrow shoulder designated for part-time use.

Shoulders less than 3.66 m (12 feet) wide typically requires a design exception if they are designated for part-time shoulder use. If an entire roadway is repurposed, and general-purpose lanes are reduced to less than 3.66 m (12 feet) wide to accommodate part-time shoulder use (for any shoulder width), a design exception is also required.

Shoulder Width

It is desirable to leave 0.5 m of pavement beyond the portion of the shoulder designated for part-time shoulder use to decrease the likelihood of vehicles departing the roadway and decrease pavement maintenance needs. Part-time shoulder use will require a design exception, since the remaining paved shoulder (beyond the portion of the shoulder designated for part-time shoulder use) will not meet the minimum width requirements.

12.5.4.2 Assessing Safety of Part-Time Shoulder Use

Experience to date has not identified major safety issues with part-time bus, static, or dynamic shoulder use that led implementing agencies to discontinue part-time shoulder use due to poor safety performance. Before/after collision studies of part-time shoulder use in the U.S. and internationally have not consistently indicated whether part-time shoulder use has a positive or negative effect on collision frequency.

Part-time shoulder use would likely reduce congestion-related collisions occurring during the operational hours of part-time shoulder use. Collisions related to erratic driver behavior or driver confusion may increase with part-time shoulder use.

Assessment of the safety impacts of part-time shoulder use on a given facility should begin with a review of three or more years of historical collision data. The review should consider the collision type, temporal factors (e.g., time of day, day of week), and location. Congestion-related collisions such as rear-ends occurring during times a shoulder would be open to travel, may potentially decrease with part-time shoulder use if congestion is reduced. Collisions related to erratic driver behavior or suboptimal geometry, such as run-off-road, fixed-object, or sideswipe collisions, may increase with part-time shoulder use.

Collisions related to right-side ramp-freeway may increase with part-time use of the right shoulder. The mere presence of collision types that may increase with part-time shoulder use should not prevent the application of part-time shoulder use, but the occurrence of those collision types indicates a given freeway may be a poor candidate for part-time shoulder use.

The 2014 Supplement to the Highway Safety Manual (HSM), 1st Edition, provides collision prediction models for freeways and ramp terminals, but does not explicitly model part-time shoulder use. The HSM models would have limited utility in evaluating projects that involve only adding part-time shoulder use. For this guide, HSM models were used to conduct a comparative analysis of freeways with typical lane widths and shoulder widths and freeways with an additional lane in each direction, but narrower shoulder widths (and in some cases narrower lane widths). The HSM freeway collision-prediction models indicate that implementing freeway part-time shoulder use could have the following influence on crash frequency and severity:

- Reduce property damage only (PDO) crashes
- Slightly increase fatal and injury (FI) crashes when converting existing 4- or 6-lane freeways
- Have little to no effect on FI crashes when converting existing 8-lane freeways

Overall, there appears to be a link between changes in congestion and changes in safety performance when shoulders are narrowed to implement part-time shoulder use. The application of the HSM freeway collision prediction models indicate reducing congestion (by increasing capacity) can offset the increase in collisions associated with increasing the number of lanes while reducing lane and shoulder width.

The empirical studies show that additional variables not specifically accounted for in the HSM prediction models could increase collisions associated with part-time shoulder use. Those factors include any differences between narrow general-purpose lanes and a narrow part-time "lane" on a shoulder, speed differential, influence of ramps, and upstream/downstream bottlenecks. Changes in barrier offset difference with and without part-time shoulder use can be modeled in the HSM. There may be greater changes in collision frequency with part-time shoulder use if barriers are present and they cannot be moved further back from the roadway when part-time shoulder use is implemented.

12.5.4.3 Bus Riding on Shoulders

In many urban areas, traffic congestion commonly delays bus services and adversely affects schedule reliability. -Bus use of highway shoulders to bypass congestion has been in operation in Ontario on portions of Highway 403, 417, Highway 8 and Highway 401. -**ONTARIO REGULATION 618/05** outlines the designation of Bus-By-Pass shoulders on Kings Highways.

BOS operation represents a low-cost and relatively quick strategy to improve bus running times and reliability without requiring costly expansion of the highway right-of-way.- Because the bus shoulder operations can be implemented within the highway right-of-way, minimal disruption and traffic impacts result. The shoulder bus operations also facilitate the development of rail transit-like "station stopping" service, because buses can easily enter and exit the highway.

From a highway operations and safety viewpoint the BOS use operations raise ~~a number of~~several concerns. These concerns encompass the loss of basic functions that shoulders are intended to provide (removal and storage of disabled vehicles, emergency vehicle access, and highway maintenance staging), traffic safety risks, and the added costs for maintenance and enforcement. The traffic safety concerns include:

- Conflicts at on- and off-ramps~~;~~
- Sight distance adequacy, particularly at on-ramps~~;~~
- Conflicts for motorists pulling onto the shoulder~~;~~
- Loss of safe evasive movement shelter area~~;~~
- Need for bus driver training~~;~~
- Speed differential~~;~~
- Impact on adjacent lane motorists~~;~~
- Return merge distance adequacy~~;~~
- Shoulder area debris hazards~~;~~
- Reduced clearance for buses at bridge abutments~~; and~~
- Highway drainage~~.~~

Clearly, with proper operating rules and prudent upgrades to shoulder facilities, the bus use of shoulders bypass congestion would be a success strategy.

Implementation of adequate shoulder width, shoulder pavement strength, proper signage, sufficient lateral clearance of obstruction adjacent to shoulder, modifications to drainage inlets and pavement edge rumble strips would contribute to safe and successful operation of BOS use.

12.5.4.4 Traffic Control Devices Design

The requirement of signing and pavement marking varies depending on type of part-time shoulder use. -BOS is typically implemented as unobtrusively as possible with minimal signing and no pavement marking. Extensive signing and pavement marking are detrimental to overall BOS operation because it leads some passenger car drivers to believe the shoulder is also open to them.

Dynamic part-time shoulder use requires changeable signs to notify drivers when the shoulder is open. Static part-time shoulder use has been successfully implemented in the states for decades with static signs, but dynamic signs are becoming increasingly common on these facilities and have been added to several established part-time shoulder use facilities that previously had only static signs to give a higher degree of acknowledgement to drivers of the current operating condition on the shoulder.

Pavement marking needs for dynamic part-time shoulder use is no different than static part-time shoulder use. In both cases, pavement markings need to provide sufficient guidance to drivers when the shoulder is open and when it is closed.

Dynamic part-time shoulder use requires electronic lane-use control signals to display whether the shoulder is opened or closed to traffic or, optionally, transitioning from being open to closed Static part-time shoulder use facilities can benefit from LCS as well, as they allow occasional deviation from operating hours due to disabled vehicles, off-peak special events, or other nonrecurring events.

In addition to lane control signs, changeable message signs (CMS) can be used to reinforce the open/closed status of shoulder or provide other information to drivers. High volume, urban freeways on which part-time shoulder use is typically implemented often already have CMS signs.

12.5.5 Standards and Design Exceptions

Design Variances and Flexible Design Philosophies

For retrofit facilities, trade-offs and accommodations may need to be made in comparison to applicable guidelines for affected design elements (e.g., lane width, shoulder width, lateral clearance).- As mentioned earlier in **Section 12.5.5.1.4,** the implementation of HOV lanes could involve, in many cases, geometric compromises to utilize existing structures or minimize impact and cost.

HOV lanes are governed by general freeway design standards, and exceptions or deviation from the standards would require sound justification and senior level of approval (see **Chapter 1**).

The designer needs to know what trade-offs to consider, and what protocols must be followed. As a North American example, Nevada DOT utilized a series of possible trade-offs for designing the cross section for a concurrent flow HOV lane (**Exhibit 12BM**~~Table 12.5.10~~).

12.6 Safety of Managed Lanes

Managed lanes are intended to provide faster travel speeds and better reliability than the adjacent general-purpose lanes.

Collisions on managed lanes can be related to access, congestion, and sight distance. These factors are compounded by failure to appreciate driver expectancy that differs for ML as compared to GP lanes. Adequate attention to placement of traffic control devices can help. -In addition to collisions near access points, collisions also occur within a managed lane facility. Common types of collisions within a facility include:

- Rear-end collisions due to congestion~~.~~
- Sideswipe collisions due to passing on two-lane facilities or within access zones~~.~~
-
- -Collisions caused by drivers making unexpected maneuvers at the point where access restrictions apply or to avoid debris or disabled vehicles that may block the highway~~.~~

~~Table 12.5.10~~Exhibit 12BM

Suggested Design Sequence of Trade-offs for Concurrent Flow HOV lanes

Suggested Sequence	**Cross-Section Design Change**
First	Reduce the 14-ft median (left) shoulder (for continuous enforcement) to 8 ft. Provide designated enforcement areas instead.
Second	Reduce median shoulder to typical minimum width as per Nevada DOT Standard Plans.
Third	Reduce median shoulder to 2 ft.*
Fourth	Reduce outside (right) shoulder to typical minimum width as per Nevada DOT Standard Plans.
Fifth	Reduce managed lane to 11 ft.*
Sixth	Reduce general-purpose lanes to 11 ft starting from left and moving to the right as needed. The outside lane should remain 12 ft.*
Seventh	Transition barrier shape at columns to vertical face.

*Requires design exception. (Source: Nevada DOT).

Note: that this list is provided as an example and is not intended to supersede engineering judgment in specific design applications.

12.6.1 Safety Implications of Managed Lanes Cross-Section

Research work in 2013 reported on an evaluation of the relationship between cross-section design (i.e., lane width, shoulder width, and buffer width) and safety performance for HOV lanes. Three years of collision data for 13 Southern California segments totaling 153 miles were analyzed. The segments were buffer separated between HOV lanes and GP lanes.- Collisions included those that occurred on median shoulder, in HOV lane, or in adjacent GP left lane.

Independent variables included geometric attributes and annual average daily traffic (AADT). -It was found that wider HOV lane width and wider shoulder width were associated with lower collision frequencies.- For that study, buffer width and width of the lane next to HOV lane were not found to be statistically significant. -The authors also provided case study of preferred cross-section allocation if converting a section from an HOV lane and left shoulder to a section having a buffer, HOV lane, and left shoulder. -The authors recommended inclusion of a buffer by reallocating some of shoulder width to buffer.

Another study in Florida (2015) developed collision prediction equations for freeway facilities with HOV and HOT lanes by number of freeway lanes.- Segment length and AADT were found to be significant and included. For most of models, left shoulder width was the only other significant variable.- An increase in left shoulder width was associated with decreases in collisions.- The inclusion of a 2- to 3 -ft buffer was associated with fewer fatal and injury collisions.

The findings from safety literature along with guidance in ***Highway Safety Manual*** are clear in that a reduction in a freeway left shoulder width is associated with an increased number of collisions.

Research work in California and Texas (FHWA-HOP-16-076 December 2016), California included freeways with three or four GP lanes while the Texas freeways had three to five GP lanes, indicated that reduction in a freeway left shoulder width is associated with increased number of collisions. -Safety studies for GP freeway lanes found that reduction in lane width is associated with more collisions.

- Safety improvement associated with increased left shoulder width is a reduction of collisions by 5% per additional foot of left shoulder, when there are no changes to other model variables.
- Safety improvement associated with increased right shoulder width is a reduction of collisions by 9% per additional foot of right shoulder, when there are no changes to the other model variables.
- There is a safety improvement associated with each additional lane width (see **Exhibit 12BN**~~Table 12.6.1~~).

Other research work indicated that increase in collisions associated with reductions in freeway lane and shoulder widths may be offset if reductions are done to increase number of freeway lanes. -Also, research results indicated that reductions in ML widths (shoulder, lane, and buffer width) are associated with more collisions.- It was found that narrow buffer widths (equal or less than 3 ft) appear to be associated with more collisions as compared to 4 -ft to 6 -ft buffers.

Wider envelopes are associated with a reduction of 2.8% (in Texas) or 2.0% (in California) in total freeway collisions (all severities) for each additional foot of width.- In California, wider envelopes are associated with a reduction of 4.4% in ML related collisions (fatal and injury severity levels) for each additional foot of envelope width.

~~Table 12.6.1~~Exhibit 12BN

Safety Benefit of Additional Lane

Safety of lane width (Fatal and serious injury collisions). Number of Lanes	Fatal and Serious Injury Collision Reduction of a 12-ft Lane Compared to 11-ft
2	5%
3	7%
4	10%
5	12%

12.6.2 Collisions at Access Points

Access points are common sites for collisions just as at intersections on surface streets. Collisions near access points can involve vehicles entering or leaving the managed lanes (e.g., sideswipe, striking separation device, etc.), and collisions can involve vehicles that are not changing facilities (e.g., rear-end collisions caused by drivers braking to avoid a vehicle entering the facility in front of them).- Volume of traffic, type of access and separation provided, and proximity of ML access to GP lane entrance and exit ramps may all influence collisions and these effects may vary from one facility to another.

12.6.3 Safety Benefits of Converting HOV t~~T~~o HOT Lanes

Safety benefit is a major component of benefit-cost analysis of transportation projects. Conceptually, conversion of HOV to HOT lanes could offer safety benefits. First, the underused HOV lanes may motivate solo drivers on general purpose lanes to “cheat”.~~.”~~ Illegal users of HOV lanes may be more likely to make a sudden entry when they are frustrated by large speed differential between HOV lane and general-purpose lanes and may make sudden exits when they realize the presence of police surveillance. It is evident that intermediate access and lane changes by illegal users on concurrent flow HOV lanes increased collision rates.

Truck traffic has significant impact on traffic operations and safety. -Safety concerns due to truck traffic continue to draw increasing attention of transportation engineers and policy makers who are proposing a few practical strategies such as lane restrictions and exclusive facilities. The key aspect of all these strategies lies in separating trucks from cars to create more homogeneous traffic conditions.

Researchers and practitioners have been exploring various remedial countermeasures to tackle these problems. Different truck traffic control strategies have been proposed as a mean to reduce their operational and safety impacts. A wide range of research results in favor of these strategies based on their operational performance. However, there is still very limited consensus on their safety impact. Despite some empirical findings on collision reduction, very few of them specifically examined the outcomes of the collisions in terms of collision severity.

~~Table 12.6.~~Exhibit 12BO~~3~~

Operational Impacts of Physical Design Options

Source Conversions of HOV to HOT Guidebook – FHWA 2007

<table>
<tr><th colspan="2">Physical Design Options</th></tr>
<tr><td>Concrete Barrier
Benefits:
• Reversible lane concept
• Safety from general purpose lanes
• Easier to enforce compliance
Issues:
• Users have feeling of confinement
• No way-out during accidents unless removable rail or gates are installed</td><td>Flexible Delineators (Pylons)
Benefits:
• Inexpensive and achieves visible separation
• Easy removal
• Have a way out
Issues:
• Frequent maintenance / replacement
• Safety due to vehicles able to drive through delineators
• Possible flying hazard when hit by vehicles at speed</td></tr>
<tr><td>Buffer Separated
Benefits:
• Inexpensive
• Vehicles have a way out
• Easy removal
• Easy to install
Issues:
• Safety due to vehicles cutting in and out
• Extra right-of way requirements</td><td>Non-Buffer Separated (Pavement Markings)
Benefits:
• Inexpensive
• Vehicles have a way out
• Easy removal
• Easy to install
Issues:
• Safety/enforcement issues of vehicles cutting in and out</td></tr>
<tr><td>Non-separated Shoulder
Benefits:
• Provides extra capacity without adding a lane
Issues:
• Confusion over lane use
• Lack of emergency pull outs for disabled vehicles
• May have to be rebuilt if transit buses are allowed to use.</td><td>Grade Separation
Benefits:
• Exclusive use
• Safest
Issues:
• No way out
• Lengthy construction/Expensive
• Users have a feeling of confinement
• Easier enforcement</td></tr>
</table>

12.6.4 Safety Impact of Commercial Vehicle Separation from Traffic

A large percentage of commercial vehicles, both in rural and urban areas, can degrade the speed, comfort, and convenience experienced by passenger car drivers. Some jurisdictions, to minimize these safety and operational effects, have implemented truck lane restrictions. The most common type of lane restriction addresses truck traffic. These restrictions can take the form of time-of-day restrictions, peak period bans, or route restrictions.

The dual-dual roadway consists of parallel inner lanes for autos only and outer lanes for mixed traffic. -Collision data from major highway sections with dual-dual roadways for several years was examined.- Comparative analysis showed that the severe collisions occurred in different lanes were different. -Surprisingly, the proportions of injury collisions occurred along the dual-dual roadways were higher compared with other sections of the highway.- Results also confirmed that collisions on the dual-dual roadways were more likely to be injury collisions.- As a general comment, results of deployment dual-dual roadways with car-only lanes has statistically significant impact on collision severity, indicating higher risk of having injury collisions in dual--dual lanes compared with regular mix traffic lanes. The finding suggests that other than considering collision frequency as a measure of safety, collision severity should be considered to fully assess the performance of the truck-auto separation strategies.

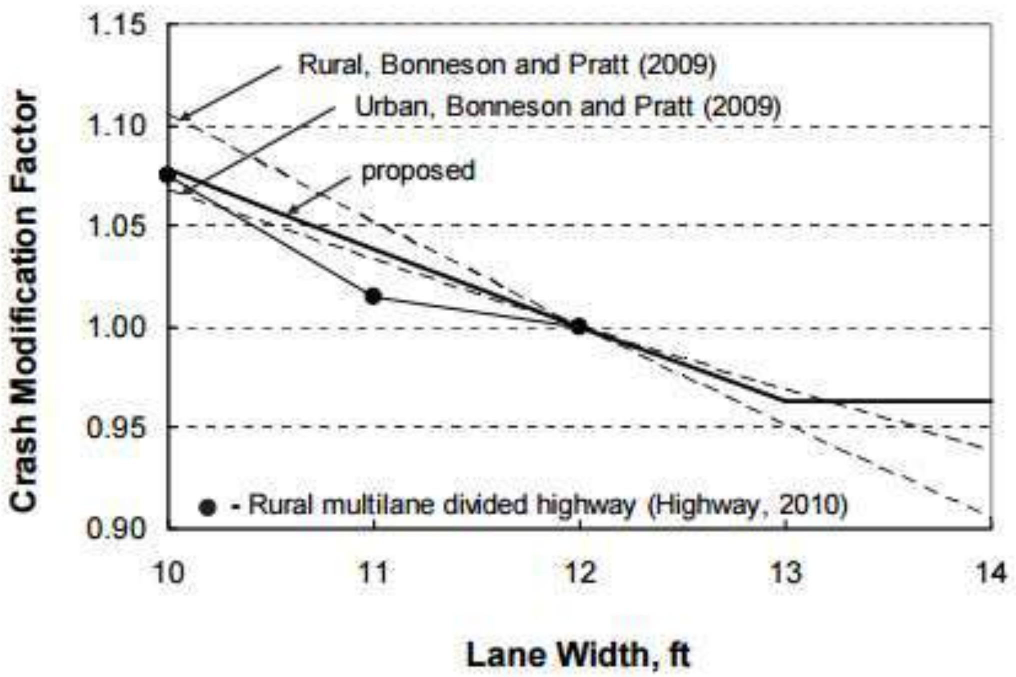
Other research work showed different results indicating that mixed-use lanes (cars and trucks) had a higher collision rate than car-only lanes and that truck related collisions were the biggest contributor in the mixed-use lanes.- The speed difference between cars and heavy trucks is the main source of safety concern. -Significant speed differential leads to more collisions.

The **Highway Safety Manual (HSM)** now includes crash predictive methods for freeways.- The researchers found that reductions in lane widths and inside (left) shoulder widths are associated with increased collisions. The proposed collision modification factor for the HSM along with the findings from other recent work is shown in **Exhibit 12BP**~~**Figure 12.6.1**~~ for lane width and ~~**Figure 12.6.2**~~**Exhibit 12BQ** for inside (left) shoulder width. The range of shoulder widths included in the study was (0.6 m to 3.6 m) 2 to 12 ft. An inside shoulder width of 6 ft was assumed as the base condition. Some agencies avoid inside shoulder widths greater than 4 ft and less than 8 ft because of concerns that drivers may attempt to seek refuge in a space that does not have sufficient width to accommodate a typical vehicle (6 ft) plus clearance (desirably 1 ft to 2 ft).

Exhibit 12BP

Proposed Crash Modification Factor for Lane Width

Source: Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges (NCHRP Project 17-45, online final report).



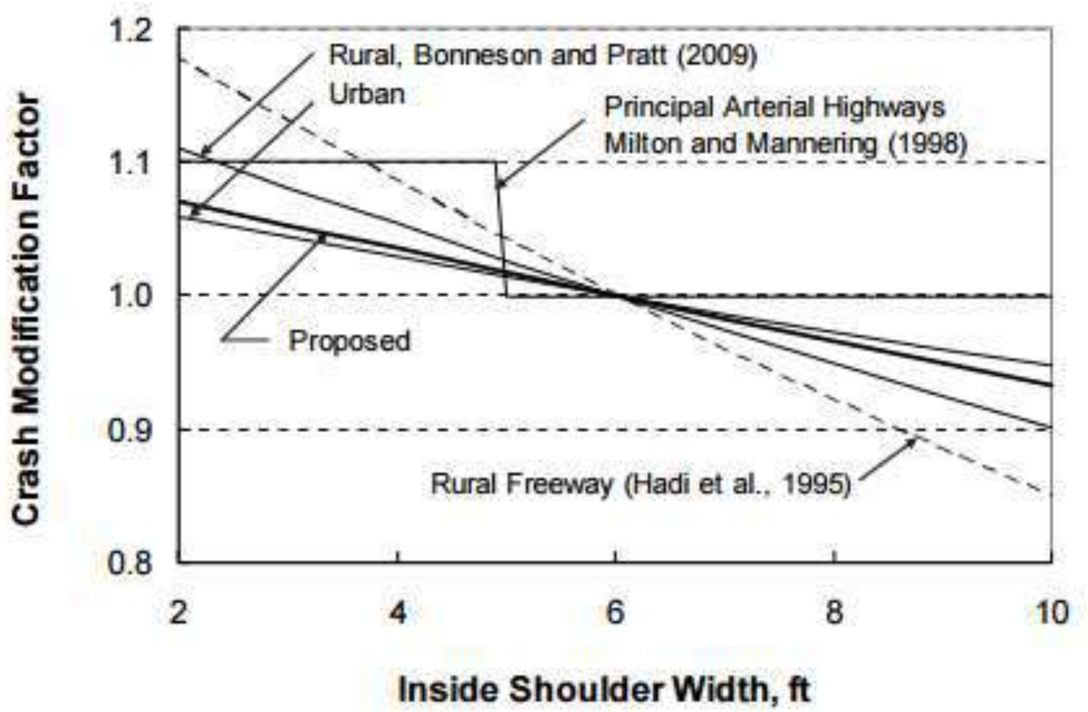
~~**Figure 12.6.1 Proposed Crash Modification Factor for Lane Width.**~~

Exhibit 12BQ

Proposed Crash Modification Factor for Inside Shoulder Width

Source: Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges (NCHRP Project 17-45, online final report).

~~*Source: Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges (NCHRP Project 17-45, online final report).*~~



~~**Figure 12.6.2 Proposed Crash Modification Factor for Inside Shoulder Width.**~~

~~*Source: Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges (NCHRP Project 17-45, online final report).*~~

12.7 Traffic Control System for Managed Lanes

12.7.1 Advanced Traffic Systems (ATS) Applications

As managed lanes become more common, road agencies have been working to develop new standards and guidelines for the traffic control devices for these new facilities.- Surveys have been conducted to investigate drivers' comprehension of signs for toll and managed lanes facilities.- Some aspects revealed are:

- Advanced destination signing is an important determinant of whether drivers will use a managed lane or not. -Distance – Destination signs and Interchange Sequence Signs should be provided in advance of all access points to and from managed lanes.
- Interchange sequence signs for managed lane exits ~~requires to be made~~needs to be more distinct to avoid confusion with signing for the general-purpose lanes.

Managed lane facilities are among the segments of the highway system which exhibit the greatest potential for FTMS/IVHS related applications and benefits:

- The intent of FTMS is to make the highway system operate more efficiently, more safely, and with less congestion; these goals are shared with managed lane applications.
- FTMS/IVHS strategies are normally applied in those corridors exhibiting significant recurring congestion to maximize potential benefits; these are also conditions suited to ML application.
- -Managed lane has the potential to operate with great flexibility and maximum efficiency through increased awareness of mixed flow conditions and flexible electronic signage and gate controls; some types of managed lanes could operate only when and as needed to avoid congestion, for example at various points throughout the day or with varying minimum occupancy rates depending on the overall freeway level of service. However, if not tied to a schedule, enforcement and driver expectations could have problems due to inconsistency.
- Managed lane is in most cases a more controlled environment than several mixed flow lanes and is used by a select group of vehicles (no trucks); management of the flow within the lane to achieve optimum efficiency will be far easier than application of IVHS on a large scale to the entire freeway system.
- One of the major HOV-related issues at present is the determination of vehicle eligibility (i.e. occupancy); advanced registration and/or electronic monitoring techniques hold some promise to resolve this problem.
- Ramp metering, and preferential treatment of HOVs at metered ramps, holds significant potential to become more efficient and effective, with monitoring and control of upstream lane volumes and gap availability.
- IVHS plans are likely to be fist applied to buses and commercial fleets before extending to the entire automotive spectrum; since bus use is a major factor in achieving the potential of an HOV/HOT facility, any technique which improves bus service is supportive of the HOV/HOT concept.
- Ridesharing and transit information will become more readily available and accurate, thereby making HOV/HOT use and carpool formation more convenient.

In summary, managed lane facilities and operation will potentially be among the most significant and easily applied components of an advanced Traffic Management/IVHS plan for a freeway corridor. –HOV/HOT use is itself one of the most effective means of reducing congestion, it is essential that HOV/HOT operation maintain a good level of service and that use of HOV/HOTs - both carpools and buses - be made as convenient and attractive as possible.

12.7.2 Incident Management

As essential element in a Freeway Traffic Management and Operations plan is Incident Management, both in reducing the risks of disruptive incidents occurring and in minimizing the consequences of incidents of traffic flow when they do occur.- Since two of the key features associated with managed lanes priority treatments are travel time improvement and reliability, incident management plays a major role in managed lanes system operations.

Typical non-recurrent incidents include traffic accidents, disabled vehicles, spilled loads, driver gawking, and adverse weather conditions.- Other irregular activities which may affect flow include freeway maintenance (including snowploughing) and construction while unusual situations such as traffic diversion from blocked parallel routes, VIP transfers, and larger scale emergencies can also occur. -Together, all these departures from "normal" operation represent the cause of the delay experienced on freeways in Ontario's urban areas.

An Incident Management Strategy, involving defined actions and responsibilities, should be developed for a corridor prior to the introduction of HOV/HOT lanes; involved agencies should include the MTO, provincial/regional police, all emergency service providers, tow truck operators, and the affected municipalities.

A Freeway Traffic Management System (FTMS) plays a large role in identifying and removing incidents while informing area motorists of the situation; some HOV/HOT -specific design features related to incident management are also appropriate:

- Adequate shoulder width, continuous throughout HOV/HOT project, for both HOV/HOT and mixed flow lanes (see **Section 12.5** for relevant design guidelines).
- W~~w~~idened shoulders where necessary for enforcement purposes (**Section 12.8.3.2**).
- P~~p~~hysical barriers between opposing traffic flows and, where adequate right-of-way exists, between adjacent HOV and mixed traffic lanes.
- A~~a~~dequate geometric provisions for lane access, egress, and termination.

Barrier-separated managed lanes have been shown to have lower collision rates than non-barrier-separated lanes.

Given that an HOV/HOT lanes effectiveness are predicated on a fast, reliable travel time, and that during peak periods they will carry a disproportionate number of persons, there is some justification to developing an incident management strategy which places highest priority on maintaining smooth HOV/HOT lane operation.

In the ~~extremely unusual~~rare event of emergency or construction conditions requiring use of the HOV/HOT lane by non-HOV/HOT users (e.g. during closure of the mixed flow lanes), consideration should be given to maintaining HOV/HOT priority to the extent possible, and to ensuring that the facility is operationally compatible (e.g. reversible lane) with the demands being placed on it.- Limiting such use to off-peak periods and using temporary or electronic signage to define the condition is highly desirable.

12.7.3 Signs and Markings

12.7.3.1 Signage

Clear, concise communication of managed lane -related facilities and regulations to all freeway users is a substantial challenge. -In addition to the normal entry, exit, and directional signage associated with any freeway lane, the specification of: a) vehicle eligibility; and, b) time of managed lane operation are required. -Furthermore, the dynamic nature of many managed lane applications provides opportunities for use of changeable signs.

O. Reg. 620/05: HIGH OCCUPANCY VEHICLE LANES, October 2018, includes description of the static signs for HOV lanes.

Also, for the HOT lanes pilot project (16.5~~-kilometre~~ km section of the QEW, in both directions, between Trafalgar Road in Oakville and Guelph Line in Burlington) signs:

- HOT lane signs marking the far-left lane
- Markers painted on the road, including diamond markers and a striped buffer zone that separates the HOT –lane from other lanes

12.7.3.2 Pavement Markings

Use of standard pavement markings and colours is recommended for managed lane facilities. For example, the HOV pavement markings are white for concurrent flow and yellow for lines separating opposing flows; solid stripes where vehicles are not permitted to cross and dashed stripes where crossing is allowed.

A buffer zone between a concurrent flow HOV lane and a mixed flow lane should be delineated by solid white stripes. -If no access restrictions are placed on the HOV lane or if it reverts to mixed flow usage during part of the day, elimination of the buffer and use of standard white dashed striping should be used; in such a case, lane designation will rely entirely on signage.

In the Ontario context, the use of diamond symbol as a pavement marking would be appropriate, however, only for full-time HOV lanes (O. Reg. 620/05: HIGH OCCUPANCY VEHICLE LANES, October 2018).

12.7.3.3 Changeable Message Signs

A changeable message sign (CMS) is a traffic control device that is displaying one or more alternative messages and can have a blank mode when no message is displayed. -CMSs can be used to change speed limit for traffic or ambient conditions for managed lanes.- CMSs are most appropriate when travel conditions change or where operational approaches are varied throughout the day, week, or in real time. A CMS may be used to supplement, substitute, or be incorporated into preferential lane regulatory signs. Also, CMSs can display tolling information that varies by time of day and type of vehicle.

When locating pricing signs, the designer should consider appropriate distance needed between the sign and the access point to provide drivers with ample time to make their decision about whether to enter the priced lane.- Driver workload is high near access points due to lane changing, weaving, and speed maintenance.- For this reason, pricing signs should not be placed immediately at the gore point of the access point.- Pricing signs should be placed upstream, so driver has time to decide whether to enter and then has adequate time to complete the vehicle maneuvers to do so. Drivers must be able to rely on information provided by the CMS.

12.7.3.4 Advanced Warning System

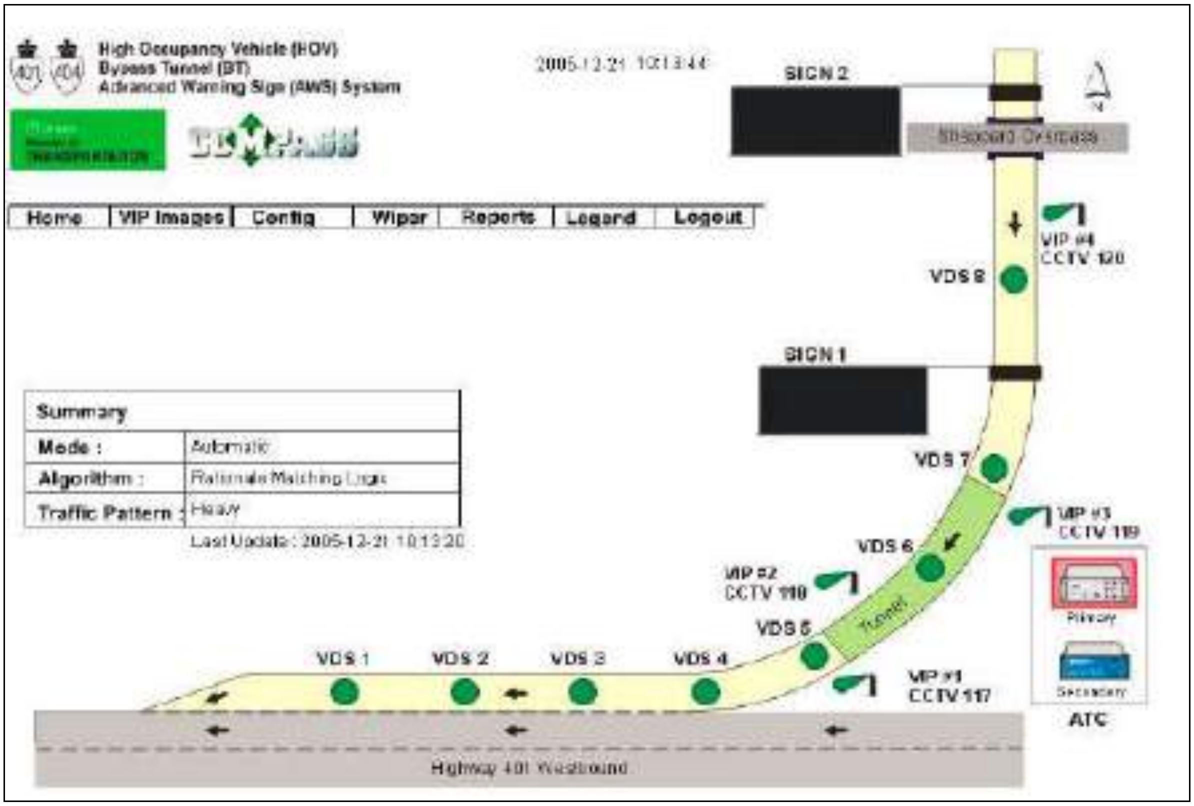
An Advance Warning System (AWS) was successfully commissioned with the HOV lane opening on December 13, 2005 for Highway 404 High-Occupancy Vehicle (HOV) tunnel. The AWS is an automated system designed to improve tunnel safety, reduce the potential for both primary and secondary collisions, and to reduce incident response times (**Exhibit 12BR**~~**Figure 12.7.1**~~).

The AWS is fully meeting and exceeding the original goals for improved motorist safety and incident management. The warning messages provided on the signs has exceeded the degree of safety of a multi-million-dollar geometric realignment, however at a fraction of the cost. This system is the first of its kind in North America and will set the new standard for exceptionally safe and efficient freeways in Ontario.

The AWS field equipment consists of eight double-loop Vehicle Detector Stations (VDS), four stationary colour Closed Circuit Television (CCTV) cameras, one Video Imaging Processing (VIP) analyzer, two Variable Message Signs (VMS) and two Advanced Traffic Controllers (ATC), refer to **Exhibit 12BS~~Figure 12.7.2~~.**

Exhibit 12BR
Highway 404 Tunnel Automated Warning Message

Exhibit 12BS
Schematic Map of Hwy 404 AWS
~~**Figure 12.7.1 Highway 404 Tunnel Automated Warning Message**~~



~~Figure 12.7.2 Schematic Map of Hwy 404 AWS~~

The eight double-loop Vehicle Detector Stations (VDS) are located before, within, and after the tunnel.– A total of three VDS locations are spaced every 40 m~~eters~~ within the tunnel and the remaining five VDS are spaced from 50 to 100 m~~eters~~ outside the tunnel (**Exhibit 12BR**~~**Figure 12.7.1**~~ **and Exhibit 12BS**~~**Figure 12.7.2**~~).

All VDS within the tunnel use rectangular preformed loops installed below the tunnel's concrete floor and span from wall-to-wall to capture vehicles both within the lane and the right shoulder. The VDS outside the tunnel use MTO COMPASS standard diamond loops in the base asphalt centered within the lane. –All VDS loops are connected to the AWS single roadside traffic cabinet and provide vehicle presence indications concurrently to two Advanced Traffic Controllers.

The Advance Warning System technological solution improves the operational management of incidents within the tunnel via the addition of the automatic video-based incident detection system. Traffic problems can be detected quickly, and the digital video recording feature enables detailed information for incident response and analysis and emergency services can be notified soon, potentially resulting in saved lives.

The AWS is designed to ensure that motorists are aware of imminent congestion conditions or traffic problems in the tunnel, thereby minimizing rear-end collisions and secondary collisions. The system operates reliably and consistently with the light and heavy traffic algorithms based on loop technology, as well as with the seamlessly integrated off-the-shelf video detection equipment. The VIP cameras improve the AWS by detecting slow or stopped vehicles quicker and more effectively than traditional loops.

Since the commencement of operations on December 2005 to April 2008, more than 200 confirmed incidents have occurred within the Advance Warning System limits.- Only one of these incidents was a single vehicle collision due to speeding. -The system was credited for significantly improving motorist safety and effectively reducing the potential for rear-end collisions (**Exhibit 12BT**~~**Figure 12.7.3**~~).

12.8 Performance Monitoring and Enforcement

Attention should be given to continual monitoring and evaluation after opening of a managed lane facility. Public and stakeholder attention to the facility will be more acute during the first year of operation, with answers desired for the following questions:

- How many people are using the managed lanes?
- Have the managed lanes improved traffic in the general-purpose lanes?
- What is the effect on carpools?
- If priced, what is the highest toll price? How much is the average toll?
- How often do account holders use the lanes?

Monitoring technology used successfully today includes vehicle sensors, automatic vehicle identification, license plate recognition, and user information systems. -Each of these components has demonstrated that it is integral in ensuring effective operation of a facility. Likewise, more comprehensive, historical data can be collected and analyzed to determine if adjustments to the overall operating strategies should be made.

Based on the experiences reviewed for many areas across North America with some form of HOV monitoring and evaluation, it found out that there are limited procedures for monitoring varying for each area.

Key elements to be considered in effectively managing and operating managed lane facilities include performance monitoring, incident management, enforcement and ongoing consideration of enhancements. Real-time monitoring of freeways and ML through closed-circuit television cameras (CCTV) and other technologies is an important component of proactive management and operation of transportation system.

Exhibit 12BT

Highway 404 and Highway 401 VMS at Tunnel Entrance

~~Figure 12.7.3 Highway 404 and Highway 401 VMS at Tunnel Entrance~~

Performance Monitoring~~.~~

ATMS provides real-time monitoring, incident detection, and rapid response capabilities.- MTO conducts ongoing monitoring and performance evaluations of HOV facilities. These efforts combine to enhance day to-day operation of HOV and freeway facilities and provide information required for operational changes.

Incident Management

~~:~~ Managing accidents and incidents on ML lanes and freeways is a key part of operational management.- Elements of an incident management program include detecting a problem, responding appropriately, clearing the incident and returning the facility to normal operations, and communicating necessary information to motorists to help manage the situation.

Enforcement

~~:~~ Enforcement of vehicle-occupancy requirements and other policies are critical to the successful operation of ML / HOV facilities. -ML enforcement programs help ensure that operating requirements, including vehicle-occupancy levels, are maintained to protect HOV travel time savings, to discourage unauthorized vehicles, and to maintain a safe operating environment. Visible and effective enforcement promotes fairness and maintains the integrity of the ML / HOV facility to help gain acceptance among users.

Ongoing Consideration of Enhancements

~~:~~ A key part of operational management philosophy is continually looking for opportunities to enhance performance of ML and freeway facilities. -Information from performance monitoring programs can be used to help identify possible areas for improvements or changes. -Examples of possible enhancements include new or expanded bus services, innovative rideshare programs and public outreach activities, motorists service patrols, ramp metering and HOV bypass lanes, and special treatments for HOVs at major destinations. -The use of new technologies, techniques, and strategies should also be considered on an ongoing basis. These approaches may include advanced transportation management systems, variable message signs, advanced traveler information systems, and other techniques.

There are few components that make up the framework for performance monitoring. These components include outlining a set of performance measures to correspond with objectives and identifying a methodology regarding the gathering of both HOV and GP lane operation data.

Evaluating HOV lanes is in some ways similar to evaluating other highway facilities – safety, vehicle volumes, and level of service are generally evaluated on both types of facilities.- HOV evaluations also examine impacts on person movement (how many people, as opposed to how many vehicles, use the lane) modal shifts (how many people changed their travel behavior to take advantage of the HOV lane), and travel time savings are all important indicators of HOV lane performance.

12 8.1 Performance of HOV Lane

Establishing a program to monitor and evaluate the performance of HOV lane can help determine if the facility meets its goals and objectives. The results of the performance evaluation provide basis for making revisions to improve the operation of the HOV system or specific lanes.~~ ~~ The performance of an HOV lane is governed by many factors including:

- L~~l~~ength of facility~~;~~
- D~~d~~esign; access and other design treatments~~;~~
- R~~r~~ates of HOV violations~~;~~
- P~~p~~resence of / coordination with transit services~~;~~
- A~~a~~vailability of park-and-ride lots supporting the different modes~~; and~~
- Supporting programs and services including rideshare matching, preferential parking and related services~~.~~

Measures of Effectiveness

Consideration of periodic monitoring of HOV lanes to determine if the improved travel time and trip time reliability, safety and satisfaction incentives are maintained, and to measure effectiveness of future improvements.

Total Person Throughput

~~: ~~A measure of how many people move past a point in a given period. Traditionally transportation agencies measure only the number of vehicles, but on HOV lanes they measure the number of vehicles, number of people per vehicle, and the number of people using transit. Increased person throughput and higher average vehicle occupancy are the goals.

Travel Time

~~: ~~To determine how long it takes HOVs, single occupant vehicles (SOVs) and freight vehicles to travel on roads with HOV lanes.~~ ~~ No increase in travel times during the afternoon rush hour is a goal.

Safety

~~: ~~Collision and incident rates on sections of highway before and after HOV lanes are established. No increase in incident and collision rates is a goal.

Enforcement

~~:-~~A qualitative measure of how enforceable HOV lane is.- Tracking the number of tickets issued and HOV lane violation rate is an indicative of police enforcement. -Minimal violation rate and maximum perception that users obey HOV rules are goals.

Air Quality
~~:-~~Less air pollution resulting in healthier air quality is the goal.

Greenhouse Gas Reduction
~~:-~~A decrease in greenhouse gas emissions is the goal.

Beginning and Ending Transitions
~~:-~~The beginning and ending of HOV lane can create weaving movements or other traffic flow problems.- Agencies monitor traffic operations to evaluate how HOV lanes affect traffic flow.

Traffic Diversion
~~:-~~There is a concern that excessive delays in general-purpose lanes may cause traffic to divert to parallel routes. Traffic counts to be taken before and after HOV lanes are established to determine if significant traffic is diverted. The goal is to minimize traffic diversion.

HOV Lane Utilization
~~:-~~A measure of how many vehicles are using the HOV Lane in a given period, and how this compares with their maximum capacity.

Transit Ridership
~~:-~~Agencies track how many people ride transit during peak periods when HOV lane is in service.

Increase in Transit Service
~~:-~~Agencies measure the increase in transit service and compare it to increase in transit ridership. This would help understand the increase in transit ridership due to the HOV project compared to normal increases in ridership that result from an increase in transit service (without an HOV lane).

Number of People per Vehicle
~~:-~~Observation of traffic to determine the number of people per vehicle during peak periods.

Park-and-Ride Use, Van Pools and Employer Programs
~~:-~~Tracking the use of Park-and-Ride and vanpools.

Public Perception
~~: ~~Survey commuters and compare responses before and after HOV lanes.

Access Points~~:~~
~~are c~~Are common sites for collisions just as collisions can commonly be found at road intersections. Collisions near access points can involve vehicles entering or leaving the managed lanes (e.g., sideswiping another vehicle, striking separation device, etc.), and collision can involve vehicles that are not changing facilities (e.g., rear-end collisions caused by drivers braking to avoid a vehicle entering the facility in front of them). -Traffic volume, type of access and separation provided, and proximity of managed lane access to general-purpose entrance and exit ramps may all influence collisions, and these effects may vary from one facility to another.

A study completed in California (2013), identified three performance measures for HOV performance evaluation as follows:

Speed Differential: (Speed in HOV Lane – Average Speed in GP Lanes).
Speed differential is a proxy for travel time savings. -For example, if traffic in the GP lane moves faster than that in HOV lane then the speed differential is negative.- If traffic in HOV lane travels at slower speeds than that in GP lanes, the HOV facilities do not provide travel time savings.

VMT Ratio: ((segment length × traffic flow in HOV lane) / {(segment length × traffic flow in HOV lane) + (segment length × average traffic flow in GP lanes)}).
This ratio measures utilization level of HOV lane by vehicle-miles but is calculated on a relative basis in comparison to GP lanes. If the ratio is greater than 0.5, it means that HOV lane carries more vehicle-miles than the average GP lane.

PMT Ratio: ((segment length × average vehicle occupants in HOV lane × average traffic flow in HOV lane) / {(= segment length × average vehicle occupants in HOV lane × average traffic flow in HOV lane) + (segment length × vehicle occupants in GP lanes × average traffic flow in GP lane)}
This ratio measures the utilization level of HOV lane by person-miles, also on a relative basis in comparison to the GP lanes.- If the ratio is greater than 0.5, it means that HOV lane serves more person-miles than average GP lane. –One of major objectives implementing HOV lanes is to carry more passengers with fewer vehicles. -Thus, PMT ratio should be given a high-priority consideration in addition to VMT ratio in terms of evaluating operational performance of HOV facilities.

Combining the VMT and PMT measures, there would be the following four possibilities:

i) **VMT Ratio < 0.5 and PMT Ratio < 0.5**: HOV lane serves fewer vehicles and people than average GP lane, which implies the potential of not optimally utilized HOV facilities. Although in this category, the HOV lane may still meet the minimum requirement by serving more than 800 vph or 1800 persons per hour according to the HOV guidelines.

ii) **VMT Ratio < 0.5 and PMT Ratio >= 0.5**: HOV lane serves fewer vehicles but move the same or higher numbers of people than an average GP lane.

iii) **VMT Ratio > 0.5 and PMT Ratio < 0.5**: HOV lane serves more vehicles but fewer people than 2 average GP lanes. This situation is unlikely due to the nature of multiple occupancy requirements in HOV lanes, but it may occur when average occupancy of GP lane traffic is greater than that of HOV lane traffic.

iv) **VMT Ratio > 0.5 and PMT Ratio >= 0.5**: HOV lane serves more vehicles and moves more people than the average GP lane, which implies the possibility of highly utilized HOV facilities. If an excessive large number of vehicles travel in the HOV lanes, however, it may begin to cause the speed differential to become negative, thus resulting in a deterioration of operations in the HOV lane.

Another North American study suggested performance measures of HOV lanes as follows:

- **Person Throughput**: Average vehicle occupancy × number of vehicles, captured using automatic traffic recorders or other surveillance technologies by vehicle class.
- **Vehicle Occupancy**: Captured through manual sampling methods, with quarterly manual counts for the HOV lanes and annual manual counts for the general-purpose lanes on a site rotational basis.
- **Travel Time Savings**: General purpose - HOV travel times; captured using surveillance technologies, will undergo internal quality control reviews and will be supplemented with manual travel time runs.
- **Travel Time Reliability**: Expressed as the percent of time HOV lane speed drops below LOS or specified average speed; captured using surveillance technologies, will undergo internal quality control reviews and will be supplemented with manual travel time runs.
- **Violations** Captured through enforcement records (i.e., citations, warnings) and reflected through average vehicle occupancy trends in the HOV lanes.

It should be noted that each type of HOV configurations can offer different advantages. Contiguous-access configuration provides flexibility for accommodating concentrated demand during peak hours while relaxing the restriction for the remaining hours.- Meanwhile, limited-access configuration provides a clear separation of flows and isolates roadways users from frequent lane-changing maneuvers except at designated access areas.- In addition, at certain freeway junction locations, limited access configurations can also prevent or discourage last-second traffic weaving maneuvers so that traffic flows can be channelized safely.

12.8.2 Performance of HOT Lanes

Effective enforcement policies and programs are essential for the successful operation of a HOT lane facility. Several strategies can be used to provide enforcement with the type of enforcement chosen largely depending upon the type of design. Buffer-separated facilities require a different enforcement strategy than a barrier separated facility.

~~Typical e~~Enforcement on HOT lanes often requires dedicated enforcement areas, which are ~~usually~~ typically located immediately adjacent to the HOT lane facility and downstream of a tolling location. This configuration allows enforcement personnel to monitor the facility as well as pursue and apprehend violators to issue appropriate citations. Where separate HOT/HOV lanes are provided (I-25 in Denver, Colorado) the tolling can be enforced with photo enforcement technology.

Enforcement areas can be classified as low-speed or high-speed and ~~usually~~ by type of separation from the general-purpose lanes. The following descriptions and guidelines are provided by NCHRP Report 414—H*OV Systems Manual* 1998.

Performance measurement for HOT projects accomplishes four interrelated purposes:

- To ensure that the projects are functioning as efficiently as possible and to enable adjustments to operational policies if they are not.
- To quantify and validate the different benefits these facilities deliver.
- To document the application of congestion pricing as a meter on traffic demand.
- To ensure that the projects follow operational requirements placed on the facility.

HOT facilities, separation type has the most significant impact on explaining the intensity of the frictional effect, as paint-separated ML facilities are readily affected by congestion in adjacent GP lanes.

Building upon recommended practices proposed in various national guidance documents for general freeway performance monitoring and evaluation the following is an overview of performance evaluation of HOT lanes:

- Similar to HOV lanes, value-priced and HOT lane performance depends upon the ability to encourage mode shift to higher occupant vehicles through reduced travel times, increased travel reliability, and enhanced safety. This mode shift is reflected in increases in person throughput and average vehicle occupancies.
- Unlike HOV lanes, value-priced and HOT lanes also benefit from revenue generation and rely on achieving a temporal shift to encourage eligible toll vehicles (SOVs or HOVs not meeting standard eligibility requirements):
    1) ~~(1) t~~To pay a high-rate toll to take advantage of the potential travel-time savings during peak periods and/or
    2) T~~(2) t~~o alter trip times to take advantage of lesser tolls during the shoulders of the peak periods when additional excess capacity is available (i.e., peak spreading). One challenge is separating the performance of the value-priced and HOT lane effects from standard HOV lane effects.

12.8.3 Enforcement Requirements for Managed Lanes

Enforcement is a necessary part of HOT/HOV lane operations to catch violators to maintain the operational integrity of the facilities. This is a manually intensive effort and can create a traffic safety hazard. -Typically, the Law Enforcement officer first monitors HOT/HOV lane entrance points to wait for vehicles by driving within, or next to, the HOV/HOT lanes where a transponder signal is not received from the passing or entering vehicle in the lane, and then catches up and drives alongside the vehicle to pear into the windows to check for passengers.

Barrier-separated facilities, because of the limited access, are the easiest facilities to enforce. Shoulders provided to accommodate breakdowns may also be used for enforcement. Reversible facilities have ramps for the reverse direction that may be used for enforcement. Gaps in the barrier may be needed so emergency vehicles can access barrier-separated HOV lanes. -Buffer-separated and non-separated HOV lanes allow violators to easily enter and exit the HOV lane.

The role of an HOV enforcement program is to protect the integrity of the facility by deterring possible violators and promoting safe and efficient use of the managed lane (e.g. HOV lanes). Enforcement requirements reflect the need to preserve the function and safety of the facility as well as its public support/acceptance. -These enforcement needs are in addition to the normal safety, emergency, and operational duties associated with any urban freeway.- Although managed lanes can, to some extent, be designed to reduce the potential for use by ineligible vehicles, enforcement agencies still need to monitor the following functions:

- Vehicle eligibility (occupancy rate, vehicle type)
- Safety (particularly lane access/egress)
- Traffic operations (speeding, following distance, etc. in both HOV and mixed flow lanes)

Enforcement on Ontario's 400-series highway HOV lanes is critical to their success.- A key component in developing design and operational practices is the consideration of enforcement provisions. -Currently, enforcement is conducted manually by police officers.- Providing strategically located enforcement areas and observation points are keys for efficient enforcement. -The impact on safety and visibility for the overall facility during planning and design of enforcement areas and observation points should be considered.

In addition to these specific features dedicated to enforcement use, the design of the priority lane itself can affect the violation rate, and in the level of enforcement effort and associated facilities required.- A contraflow lane dedicated to bus-only operation, for example, will by its very nature attract fewer violators than a non-separated concurrent flow lane, and could be considered virtually self-enforcing.

For both operational safety and ensuring the use of the managed lane only by eligible vehicles, there are benefits from limiting or controlling the access to the lane. -Even in the case of non-separated concurrent flow facility, marking the pavement ~~so as to~~to focus transfer moves to limited zones can minimize unexpected moves.- For barrier-separated managed lanes, provisions for enforcement should be focused on the entry points, allowing the apprehension and removal of ineligible vehicles before the lane is used.

A second situation in which a stationary observation and enforcement position is effective is immediately downstream of a ramp meter or queue bypass. -Both -non-HOV queue jumping and ramp metering violators can be enforced in this way, although the latter requires the provision of a meter signal head that is visible to the enforcement officer.

Examples of recommended practice for concurrent flow HOV lane enforcement areas are illustrated in– **Exhibit 12BU~~Figure 12.8.1~~ ~~-~~– ~~12.8.7~~Exhibit 12CA** Enforcement zones for other types of HOV application (reversible flow, ramp meter bypass, etc.) can be developed in a site-specific manner.

12.8.3.1 Role of Enforcement

When enforcing HOV lane usage, enforcement officers must deal with both drivers who violate the HOV restrictions unwittingly (unaware of signage, unsure of eligibility, etc.) and those who intentionally use the HOV lane in an ineligible vehicle to bypass congestion.

Both province-wide and area-wide consistency in these areas will support the effectiveness of any enforcement strategy, and are important in ensuring public awareness, understanding and compliance.

12.8.3.2 HOV Enforcement Areas

Enforcement of Ontario's 400-series highway HOV lanes is critical to their success.- A key component in developing design and operational practices is the consideration of enforcement provisions.- It is decided to provide dedicated enforcement areas as well as a left shoulder to carry out the enforcement of the HOV lanes. These enforcement areas consist of an observation pocket and enforcement bay.

There are three major requirements for enforcement-related facilities associated with a freeway HOV/Bus lane:

- A~~a~~ place to observe traffic operations and lane violators~~;~~
- A~~a~~ place to pull over violators (preferably incorporating a means of sending apprehended vehicles back into the mixed flow)~~; and~~
- A~~a~~ safe refuge for accident/incident investigation~~.~~

In addition to these specific features dedicated to enforcement use, the design of the priority lane itself can affect the violation rate, and in the level of enforcement effort and associated facilities required.

A contraflow lane dedicated to bus-only operation, for example, will by its very nature attract fewer violators than a non-separated concurrent flow lane, and could be considered virtually self-enforcing.

For reversible flow HOV lanes, a moveable physical barrier is required at each end of the priority section to preclude any vehicle gaining access to the lane in the wrong direction.- In association with such moveable barriers there is normally a pocket area suited to use by enforcement vehicles for observing entering traffic. -A pair of enforcement officers, with one observer and one downstream officer to pull over the observed violator, is effective in this situation.

In Ontario, it was agreed upon with OPP that the preferred enforcement provision is to provide a continuous left shoulder. -In urban cross-sections that have a median barrier the desirable left shoulder width is 4.25 m and a minimum of 3.6 m. -In rural cross sections where there is a grassed median and no median barrier, a minimum left shoulder of 3.0 m is acceptable.

Where physical constraints preclude the ability to provide a continuous wide left shoulder, localized median shoulder widening would be undertaken to create an enforcement area.

Enforcement areas are to be a minimum of 400 m long and a desirable length of 500 m is preferred to allow for enough opportunity for vehicles to re-enter the HOV lane. -Enforcement areas are to be located approximately every 3 km.

Highway designers should avoid locating the dedicated enforcement areas in advance of a downstream curve or within the limits of an access / egress zone.

Consultation with OPP representatives are~~is~~ recommended on HOV lane design projects to examine the unique enforcement needs of HOV facilities.

Alternative Enforcement Areas:

- Continuous paved median 4.25 m or wider in both directions for the length of the HOV facility. If space is available, additional enforcement areas may be built in conjunction with the 4.25 m median.
- When 4.25 m continuous paved median shoulders are not possible, paved bi-directional enforcement areas spaced 3.2 km to 4.8 km apart should be built. A separation in the median barrier should be provided for CHP motorcycle officers to patrol the HOV facility in both directions of travel.
- Where median width is limited, some combination of 1 and 2 should be included.
- Paved directional enforcement areas spaced 3.2 km to 4.8 km apart and staggered to accommodate both directions when space limitations do not allow any of the above outlined considerations.
- Where space is limited, directional enforcement areas located wherever right-~~-~~of-~~-~~way is available.

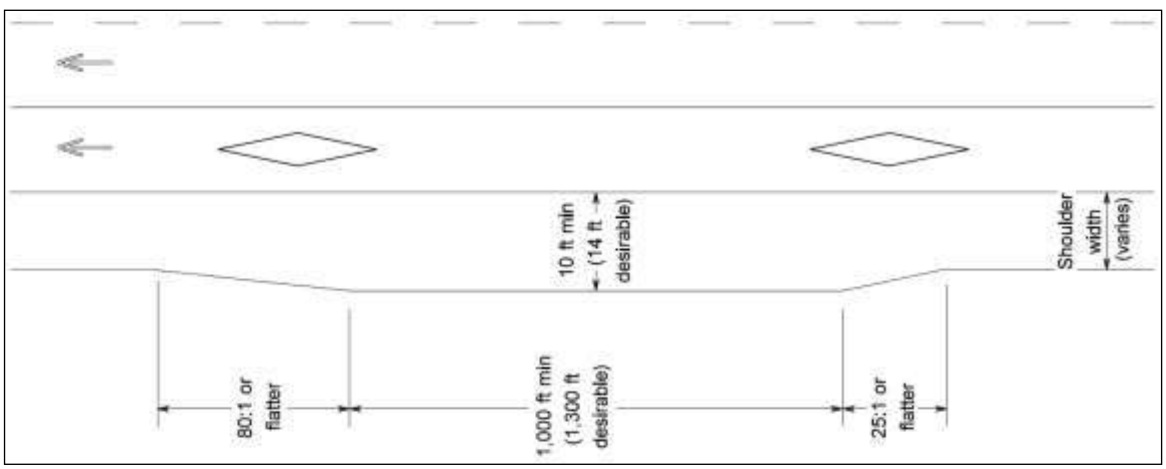
New HOV facilities should be built to provide adequate enforcement areas. Also, consideration should be given to adding enforcement areas to existing facilities where violation rates are consistently above 10%.

Exhibit 12BY~~Figures 12.8.5, –~~ ~~12.8.6~~Exhibit 12BZ, ~~12.8.7~~Exhibit 12CA, ~~12.8.8~~Exhibit 12CB, ~~12.8.9~~Exhibit 12CC, and ~~12.8.10~~Exhibit 12CD illustrate North American practices for enforcement areas for different design conditions

Exhibit 12BU

Enforcement Area one direction only

Source: WSDOT Design Manual July 2018



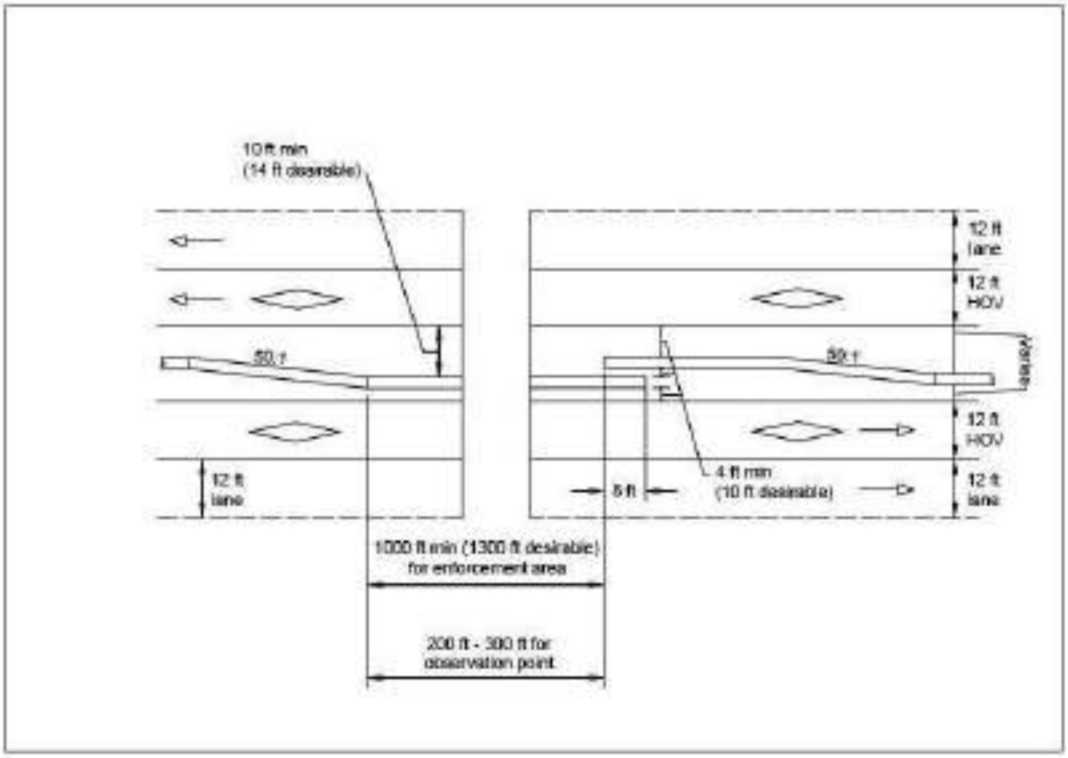
~~**Figure 12.8.1 Enforcement Area one direction only**~~

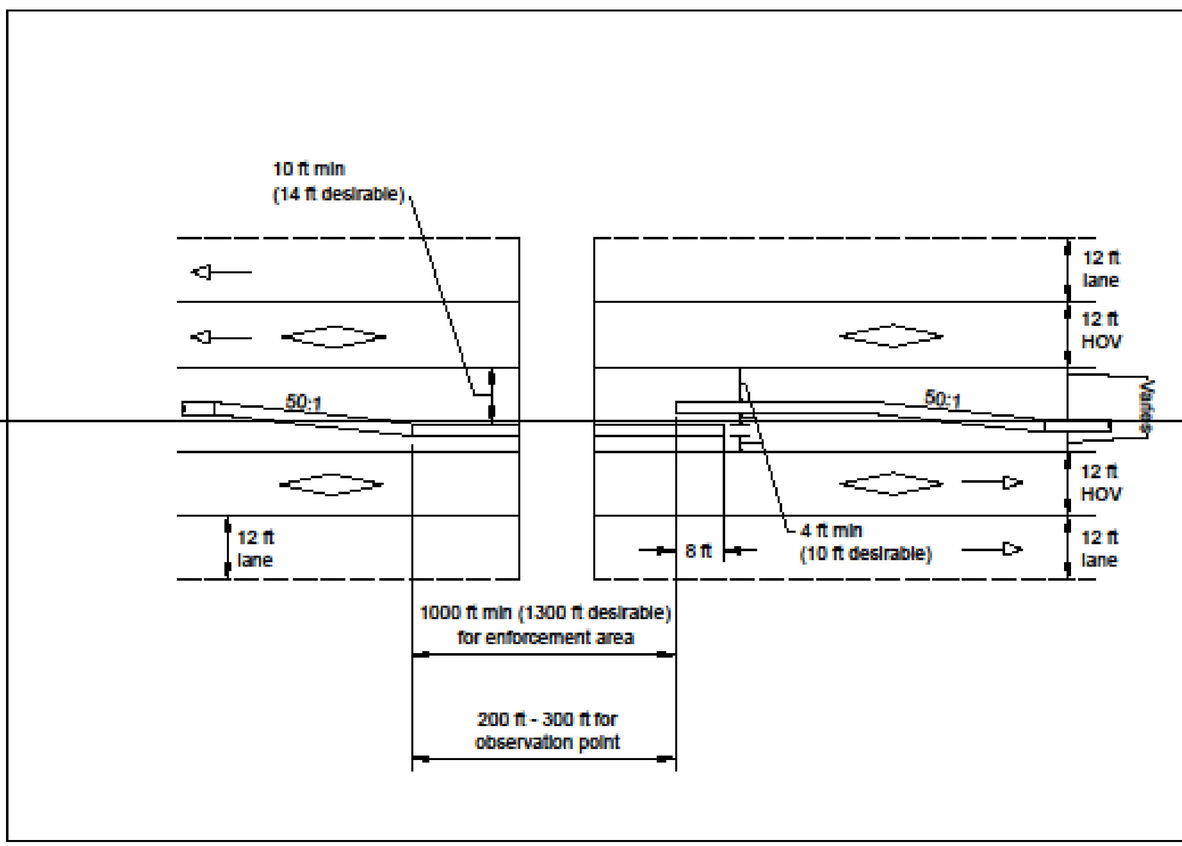
Exhibit 12BV

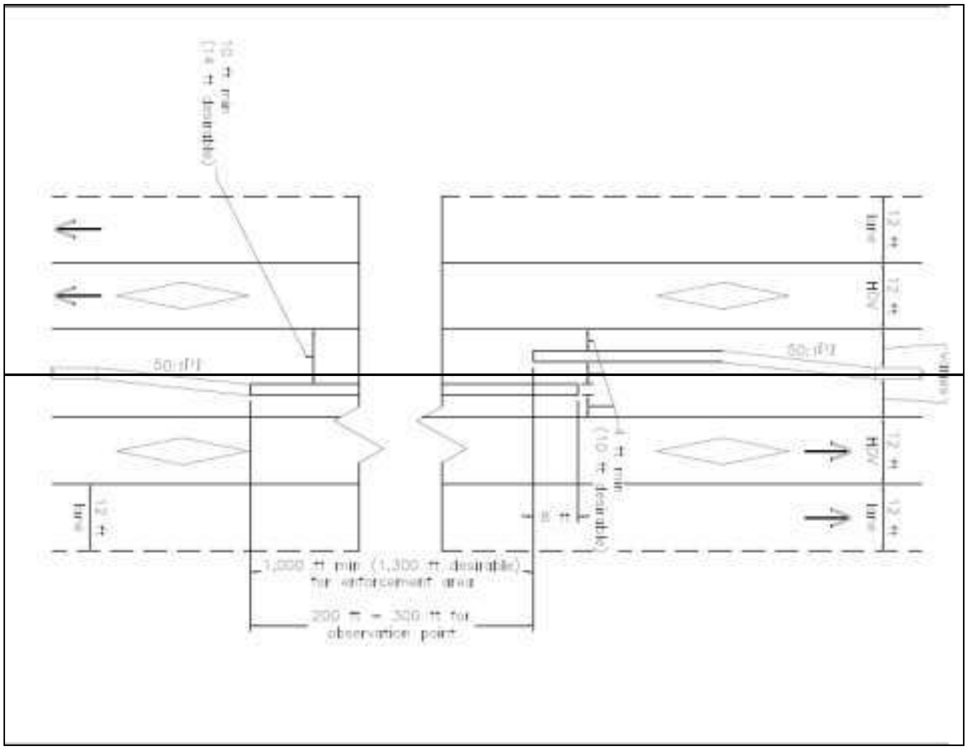
Enforcement Area Median

Source WSDOT Design Manual June 2009

~~*Source: WSDOT Design Manual July 2018*~~


10 ft min
(14 ft desirable)
12 ft
lane
12 ft
HOV
50:1
50:1
Varies
12 ft
HOV
12 ft
lane
12 ft
lane
8 ft
4 ft min
(10 ft desirable)
1000 ft min (1300 ft desirable)
for enforcement area
200 ft - 300 ft for
observation point


10 ft min
(14 ft desirable)
12 ft
lane
12 ft
HOV
50:1
50:1
Varies
12 ft
HOV
12 ft
lane
12 ft
lane
8 ft
4 ft min
(10 ft desirable)
1000 ft min (1300 ft desirable)
for enforcement area
200 ft - 300 ft for
observation point

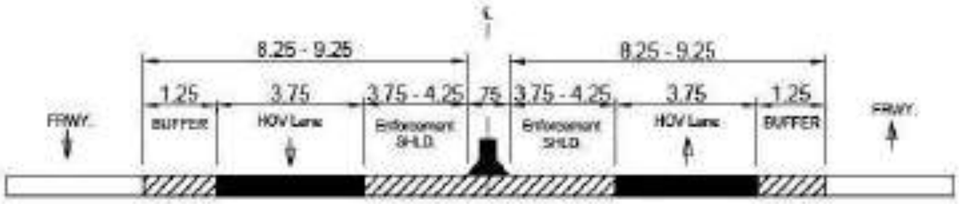


~~**Figure 12.8.2 Enforcement Area Median**~~

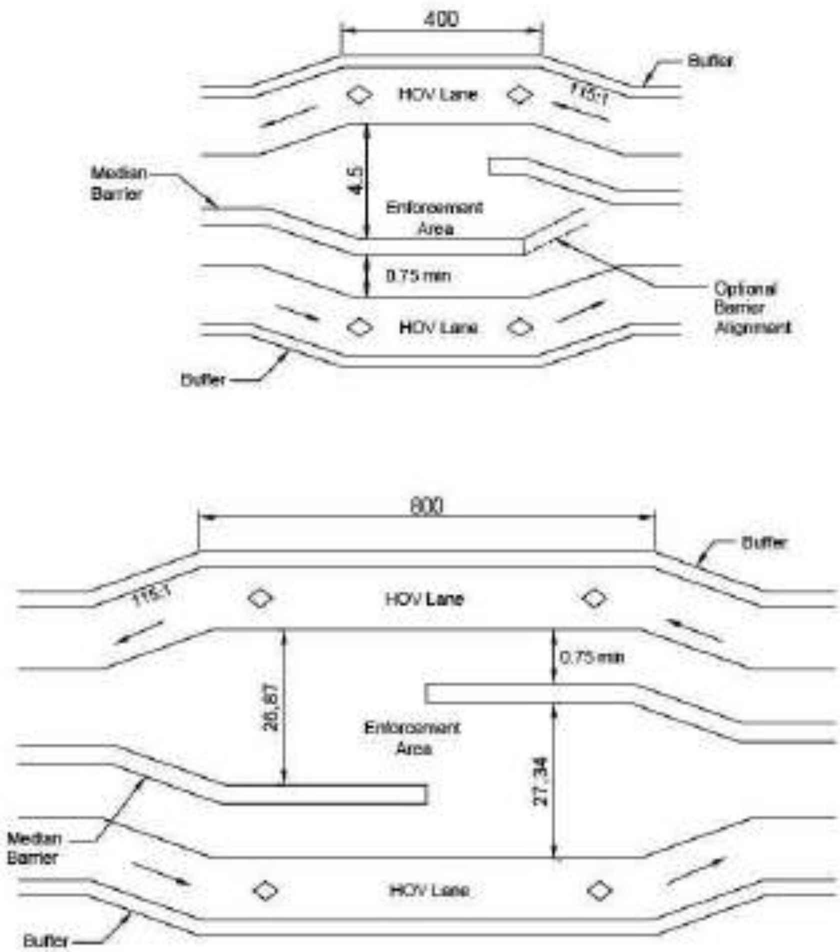
Exhibit 12BW

High-Speed Enforcement Areas

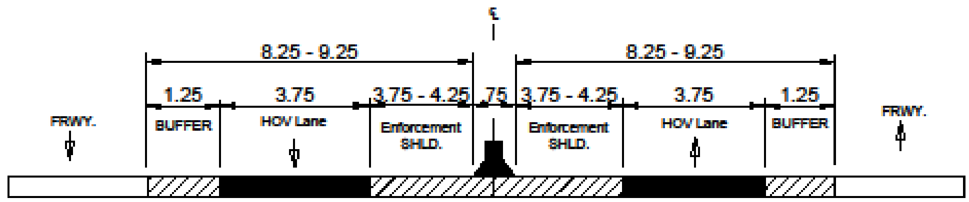
~~*Source WSDOT Design Manual June 2009*~~



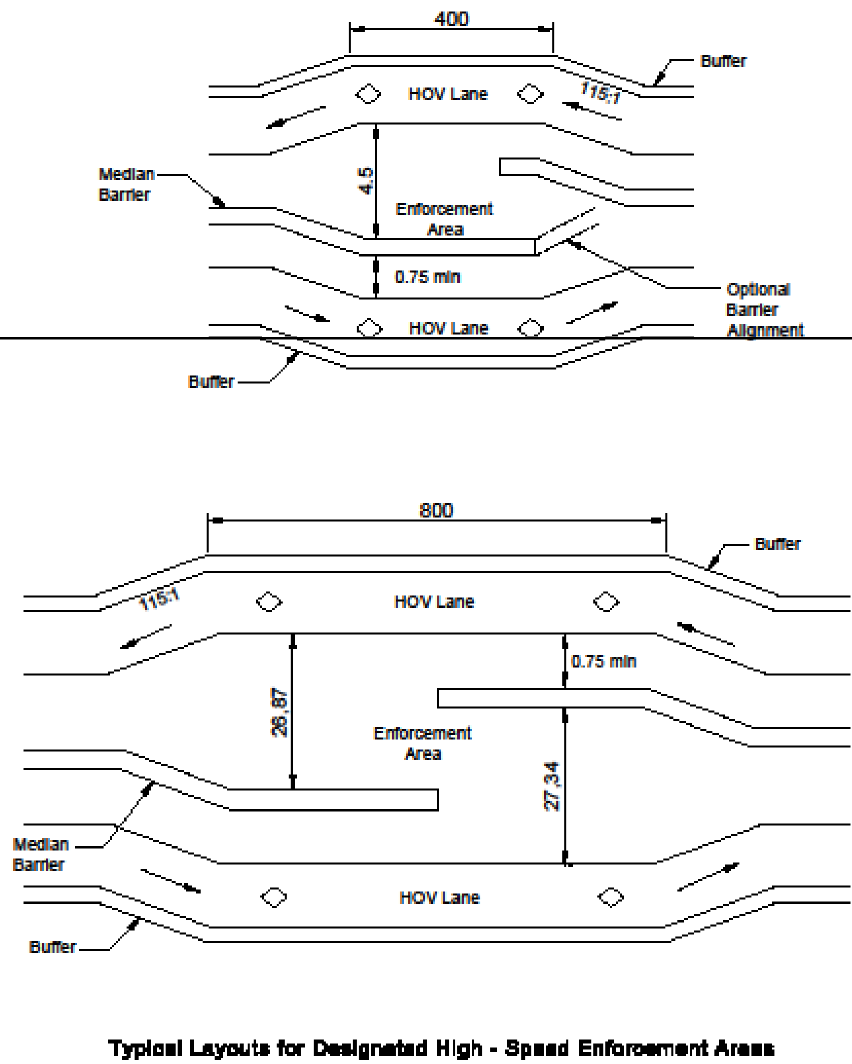
High - Speed Enforcement Areas along Two - Way Buffer - Separated HOV Facilities



Typical Layouts for Designated High - Speed Enforcement Areas



High - Speed Enforcement Areas along Two - Way Buffer - Separated HOV Facilities



Typical Layouts for Designated High - Speed Enforcement Areas

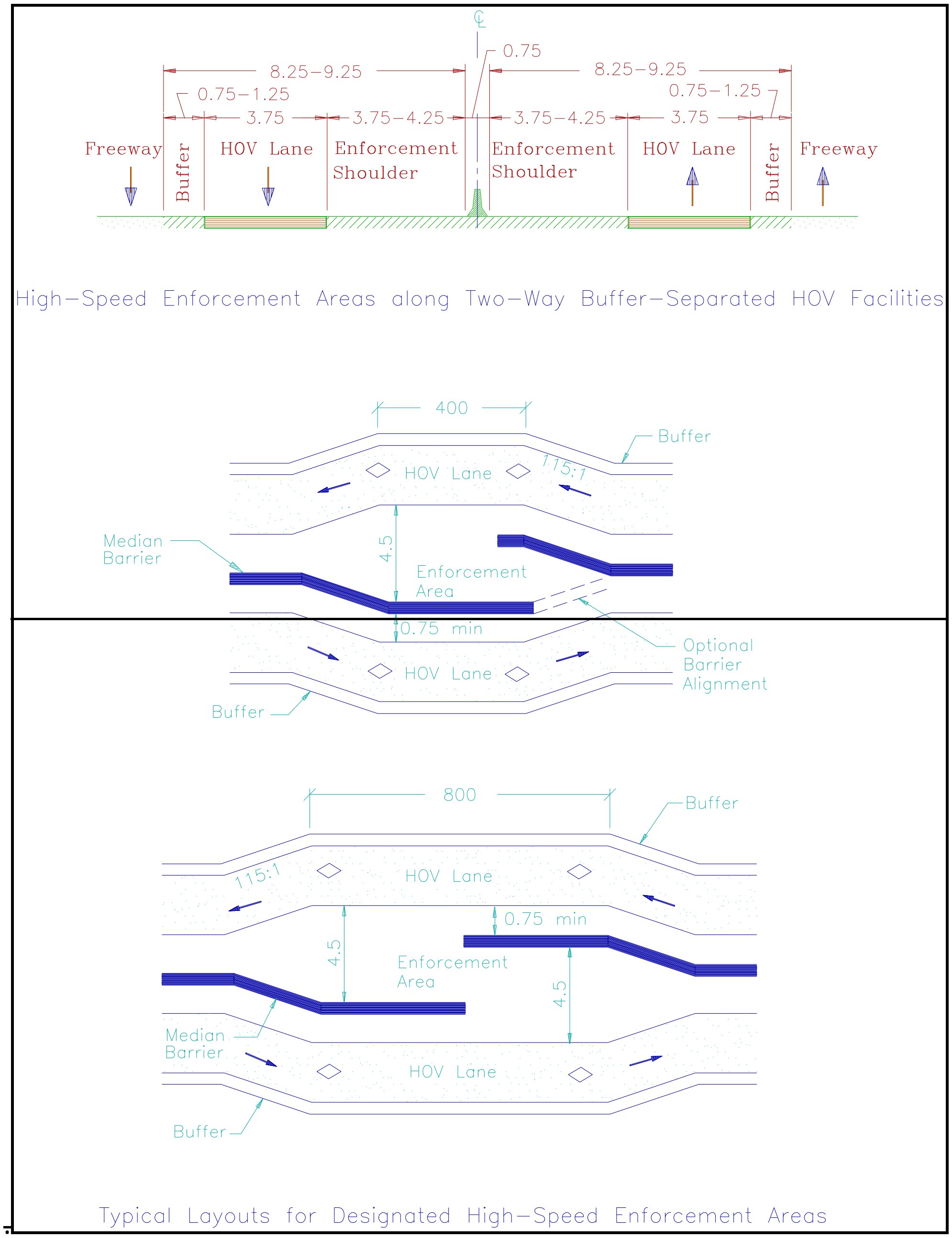
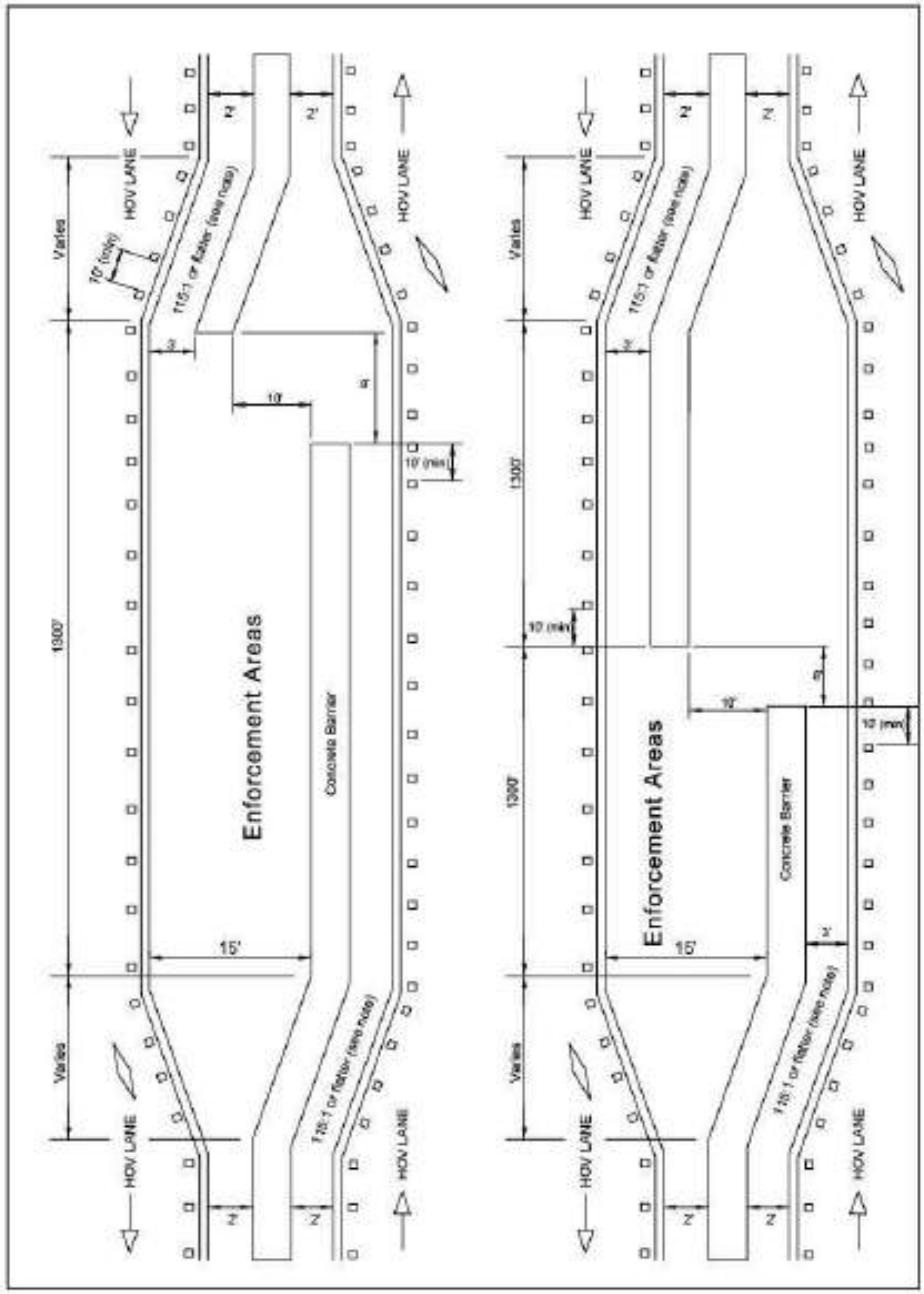


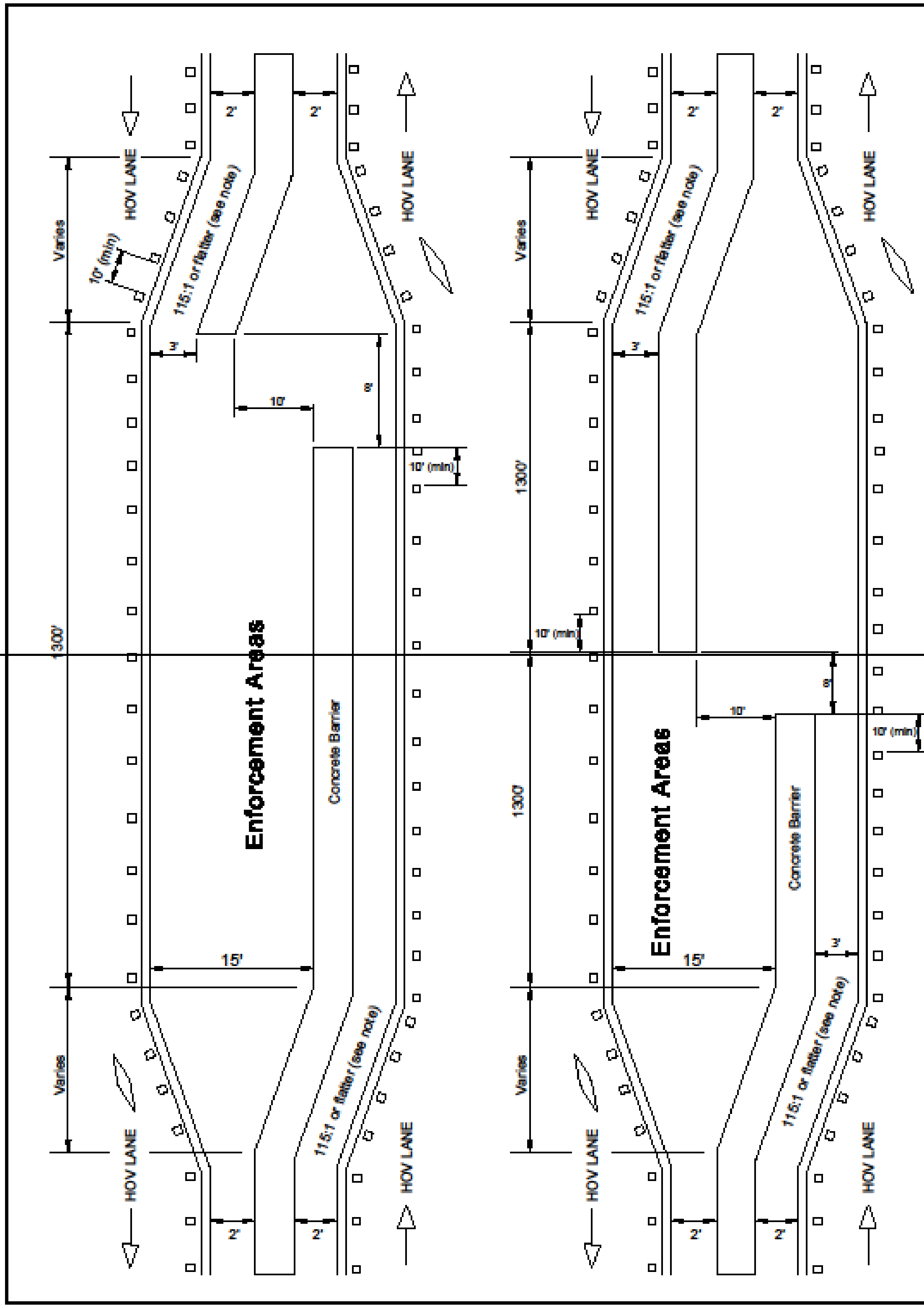
Exhibit 12BX

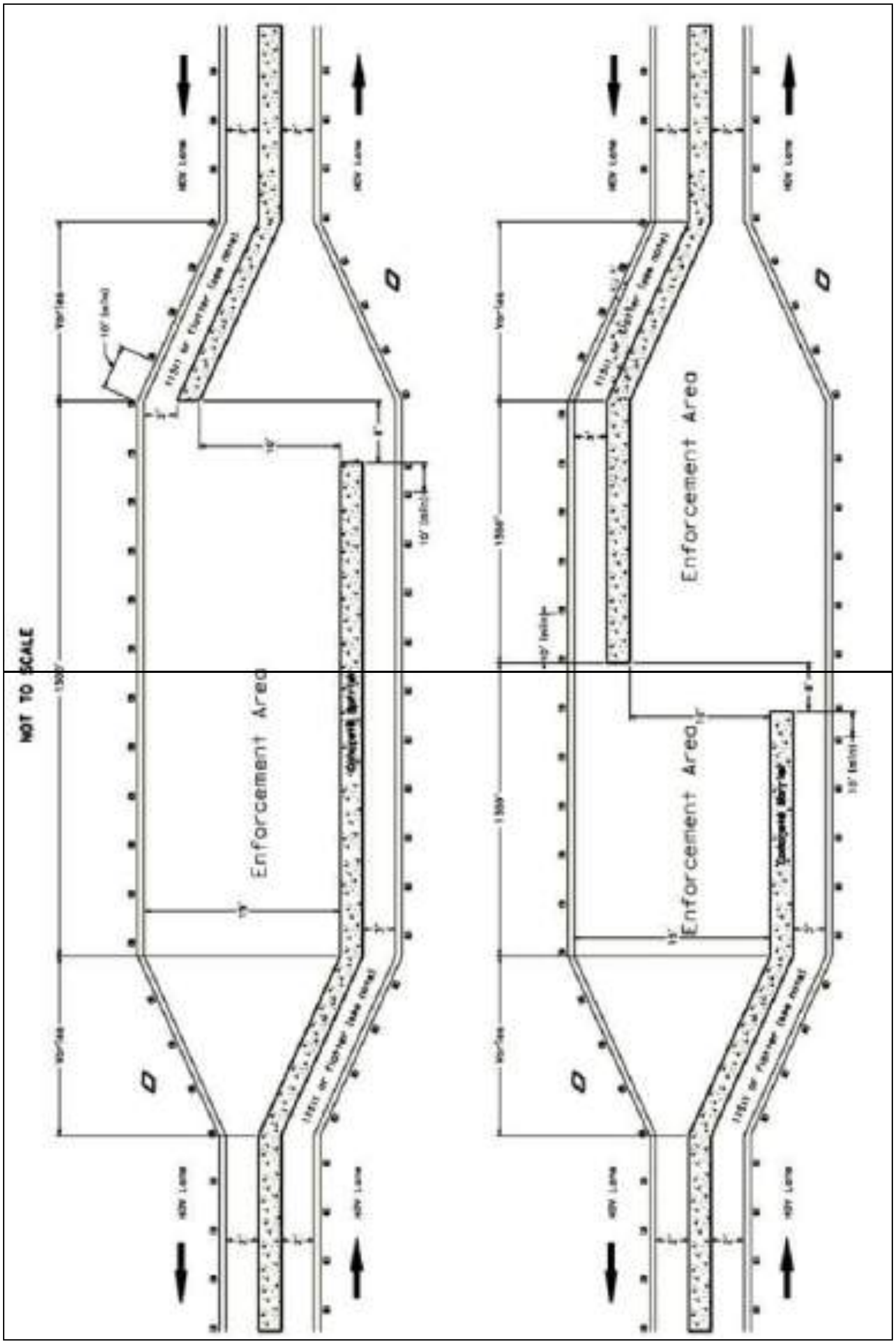
Directional Enforcement Areas for Narrow Medians

Source: HOV Guidelines California Jan 2018

~~**Figure 12.8.3 High-Speed Enforcement Areas**~~


HOV LANE
Varies
1300'
2'
10' (min)
115:1 or flatter (see note)
10'
8'
Enforcement Areas
Concrete Barrier
15'


HOV LANE
HOV LANE
2'
2'
Varies
10' (min)
115:1 or flatter (see note)
3'
10'
8'
10' (min)
1300'
Enforcement Areas
Concrete Barrier
15'
Varies
115:1 or flatter (see note)
HOV LANE
HOV LANE
2'
2'
Varies
115:1 or flatter (see note)
3'
1300'
10' (min)
10'
8'
10' (min)
1300'
Enforcement Areas
Concrete Barrier
15'
3'
115:1 or flatter (see note)
Varies
HOV LANE
HOV LANE
2'
2'

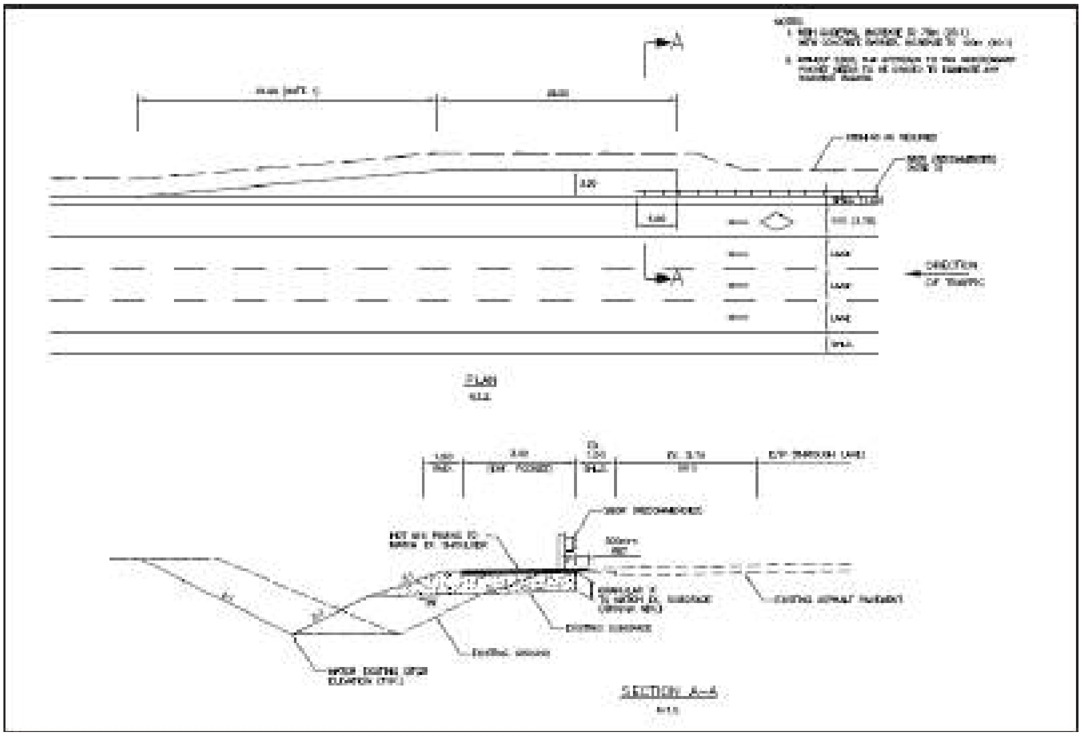


~~**Figure 12.8.4 Directional Enforcement Areas for Narrow Medians**~~

~~*Source: HOV Guidelines California Jan 2018*~~

Exhibit 12BY

Observation Pocket for Bus Bypass Shoulder (MTO Best Practice)

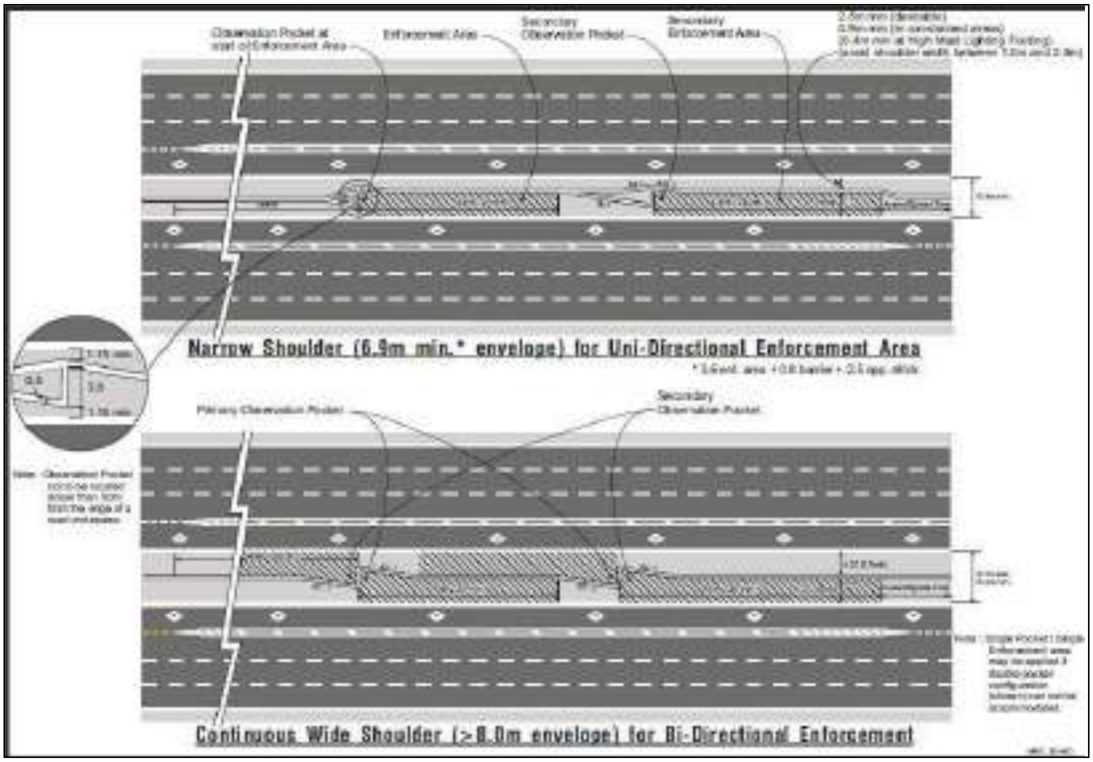


~~**Figure 12.8.5 Observation Pocket for Bus Bypass Shoulder (MTO Best Practice)**~~

Exhibit 12BZ

Double Observation Pocket and Enforcement Area Design for Median HOV Lanes

(MTO Best Practices)



~~Figure 12.8.6 Double Observation Pocket and Enforcement Area Design for Median HOV Lanes~~ ~~*(MTO Best Practices)*~~

Exhibit 12CA

HOV Signage at Enforcement Area

(MTO Best Practices)

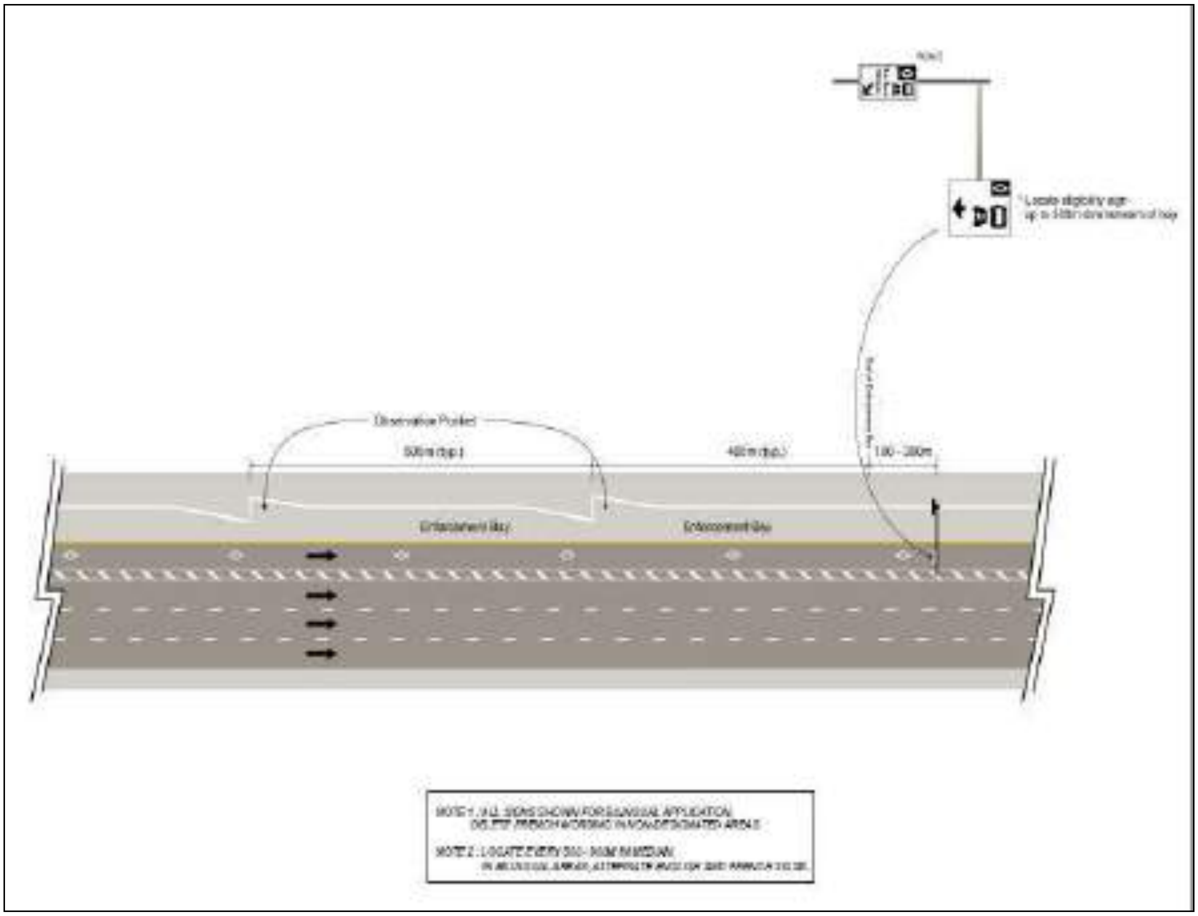
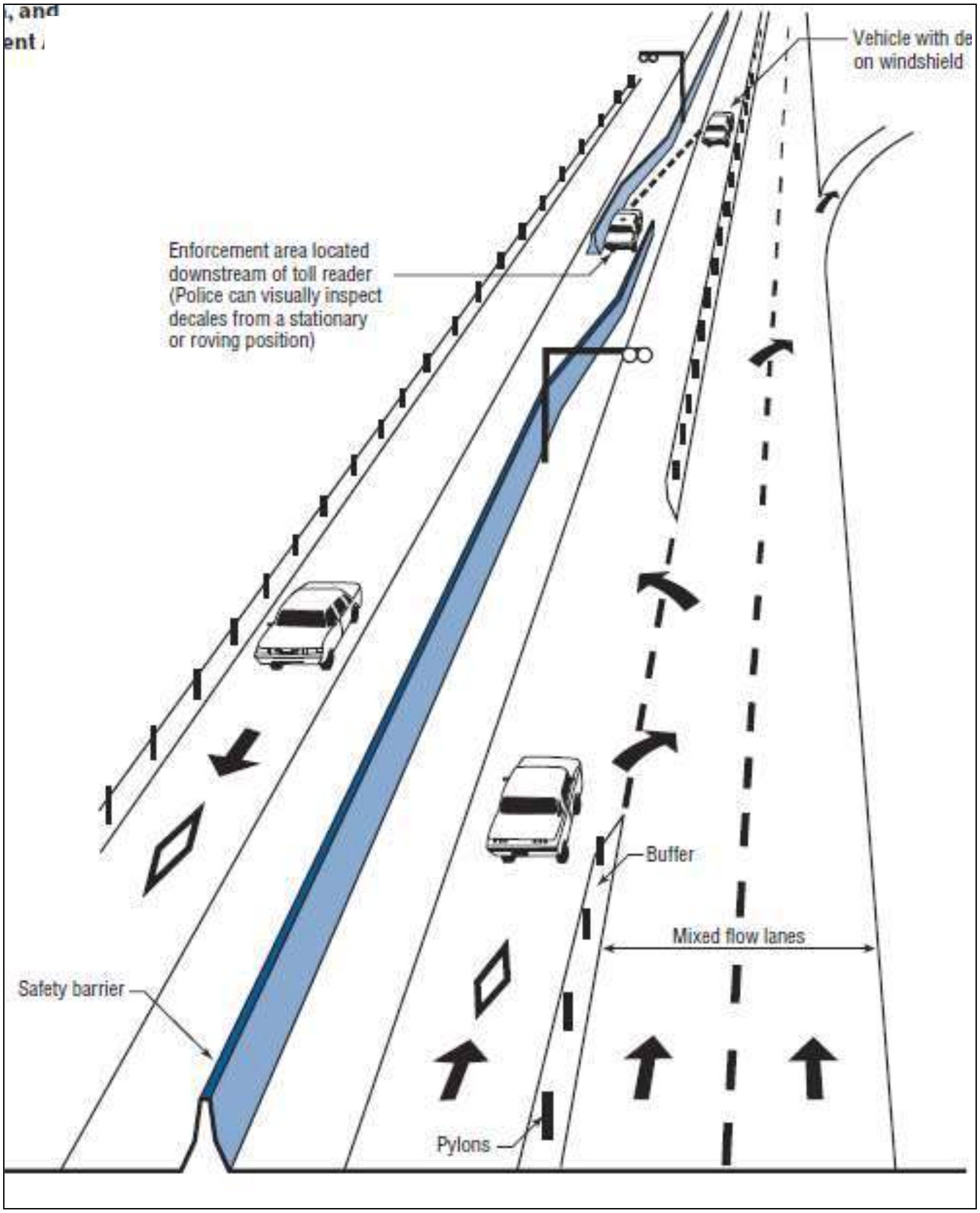


Exhibit 12CB

HOT Lane Access, Electronic Toll Collection and Enforcement Area

Source: FHWA A Guide for HOT Lane Development

~~**Figure 12.8.7 HOV Signage at Enforcement Area** *(MTO Best Practices)*~~



~~**Figure 12.8.8 HOT Lane Access, Electronic Toll Collection and Enforcement Area**~~

~~*Source: FHWA A Guide for HOT Lane Development*~~

12.8.3.3 HOV Violation Rates

The percentage of HOV lane users who commit violations on the Highway stretches that contain such lanes during the peak period, are required to be monitored. There are two violations that are of focus, and these are Buffer Zone Crossing Violations and Vehicle Occupancy (VO) Violations.

A Buffer Zone Crossing Violation is one where a motorist changes lane in to, or out of, an HOV lane at an improper location.- There are pavement markings that indicate inappropriate locations to change lanes; the Buffer Lane marking.- These locations are not suitable for ingress, or egress, into the HOV lanes.- Drivers who ignore these lane markings are in violation.
A Vehicle Occupancy Violation is one by which a driver who does not have a minimum of two occupants (including him or herself) in the vehicle, makes use of the HOV lane.

12.8.4 Enforcement Shoulder and Observation Pockets

All enforcement shoulders or zones should be at least 4 m wide (13 feet) as shown in **Exhibit 12BY** ~~**Figure 12.8.5 -**~~**–** **Exhibit 12CA**~~**Figure 12.8.7**~~ ~~in order to~~to allow a safe movement within the area; length, including access and egress tapers, should be designed in accordance with the entering and exiting vehicles speeds. The optimum design is a full width breakdown shoulder extending the length of the facility; where adequate right-of-way is not available, periodic shoulder widening to the necessary width is required (in concurrent flow median lanes the widened shoulders can alternate between one direction and the other within a constrained width median).- Enforcement areas should not take the form of a wide buffer between HOV and mixed flow traffic.- One effective deterrent to would-be violators can be the provision of a turnaround, if space is available, to release the apprehended vehicle in the opposite direction.

Examples of the design of physical facilities related to enforcement activities are illustrated in **Exhibit 12CC**~~**Figures 12.8.9**~~ to **Exhibit 12CE**~~**Figures 12.8.11**~~ for Bi-directional Enforcement Area for Wide and Narrow Medians.

12.8.4.1 Enforcement for Part-Time Shoulder Use

The success of part-time shoulder use depends on the extent to which drivers comply with posted hours of operation or lane-use controls, as well as any vehicle restrictions. Enforcement of Bus on Shoulder (BOS) lanes is focused on use of the shoulder by non-buses, and enforcement of static and dynamic part-time shoulder use is more focused on use of the shoulder outside of hours of operation.

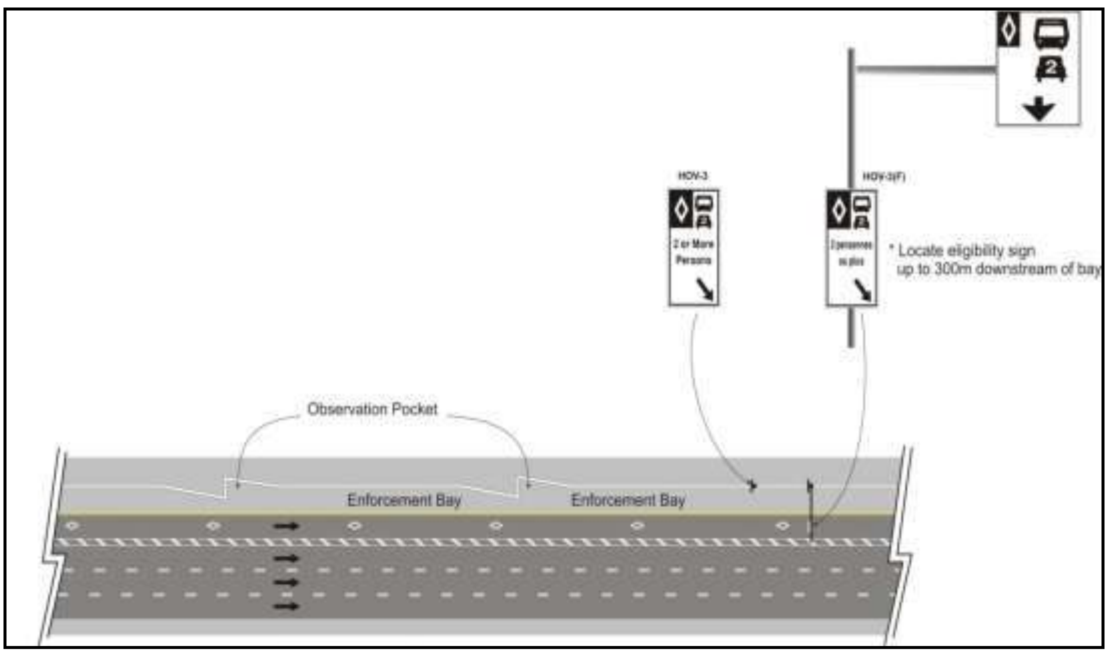
With increased likelihood of vehicles on the shoulder, including violators when the shoulder lane is closed, police conducting routine enforcement would target areas with downstream pull over opportunities such as exit ramps, emergency turnouts large enough for two vehicles, and so forth. Ultimately, law enforcement personnel should be engaged in planning and design of shoulder lanes and design needs for enforcement elements should be incorporated.

On dynamic part-time shoulder use facilities, lane control technology would include mechanisms for providing real-time information to police officers in the field about the status of the shoulder, when it is opened / closed, and the current lane assignment displays.

On BOS facilities, shoulders can still be used by police to pull over vehicles, and bus drivers are trained to re-enter general purpose lanes when a shoulder is obstructed.

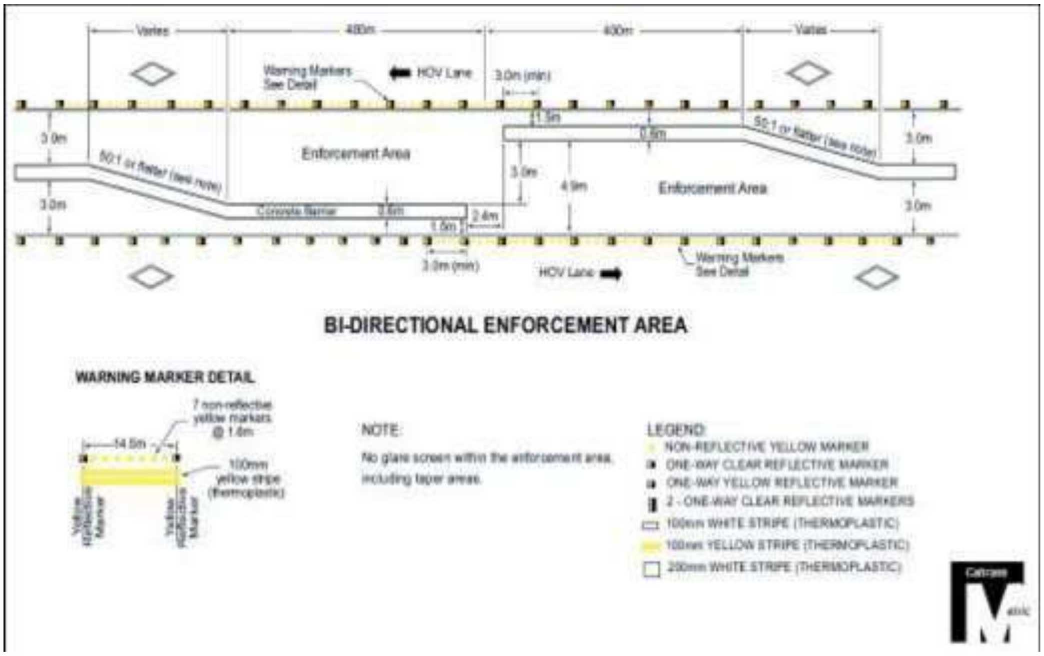
Exhibit 12CC

Signage at the Enforcement Bay and Observation Pocket



~~**Figure 12.8.9 Signage at the Enforcement Bay and Observation Pocket**~~

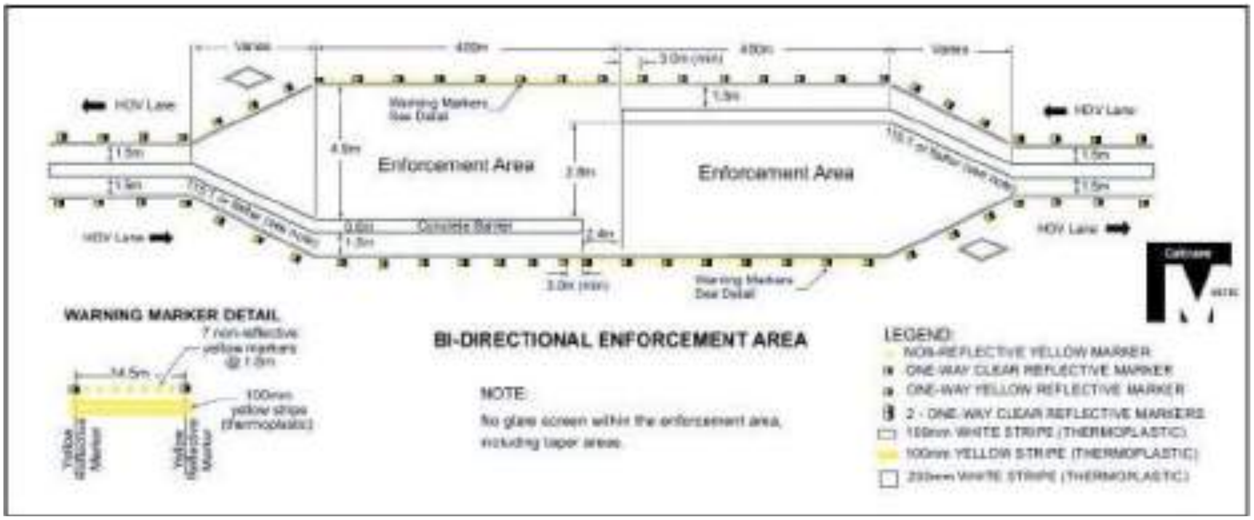
Exhibit 12CD
Bi-directional Enforcement Area for Wide Median



~~**Figure 12.8.10 Bi-directional Enforcement Area for Wide Median**~~

Source: Caltrans (*53*). This figure is solely intended for use in the California Department of Transportation's ("Caltrans") High-Occupancy Vehicle Guidelines as examples of high-occupancy vehicle lanes used within California. It is neither intended as, nor does it establish, a legal standard for use in other environments. The figure is for the information and guidance of the officers and employees of Caltrans. The figure is not a substitute for engineering knowledge, experience, or judgment. The examples given herein are subject to amendment as conditions and experience may warrant.

Exhibit 12CE
Bi-directional Enforcement Area for Narrow Median



~~**Figure 12.8.11 Bi-directional Enforcement Area for Narrow Median**~~

Source: Caltrans (53). This figure is solely intended for use in the California Department of Transportation's ("Caltrans") High-Occupancy Vehicle Guidelines as examples of high-occupancy vehicle lanes used within California. It is neither intended as, nor does it establish, a legal standard for use in other environments. The figure is for the information and guidance of the officers and employees of Caltrans. The figure is not a substitute for engineering knowledge, experience, or judgment. The examples given herein are subject to amendment as conditions and experience may warrant. Copyright 2003 California Department of Transportation, all rights reserved.

12.8.4.2 Opening and Closing Part-Time Shoulder Use Facilities

Opening and closing of part-time shoulder use facilities is a largely manual process. The shoulder should be inspected prior to each opening by "sweeping" (driving) the length of the facility or viewing CCTV if there is full camera coverage of the facility.- Any debris or disabled vehicles should be cleared prior to the scheduled opening time of the shoulder. If dynamic lane use control signs are present, then they can be used to keep the lane closed past the scheduled opening time if additional time is needed to clear the shoulder.

If an incident occurs while the shoulder lane is open, then it should be closed as soon as possible if dynamic lane assignment signs are present. Interagency agreements should be prepared prior to implementation of part-time shoulder use to determine which agency has the authority to close the shoulder.

BOS lanes do not need to be inspected before opening, and if buses encounter obstructions on the shoulder, then they can merge into traffic to avoid them, and dispatchers can alert buses on part-time shoulder use routes of known obstructions.

Road agencies should be cautious with introducing too much variability into the operating hours of dynamic part-time shoulder use. For example, if a shoulder needs to be opened in the morning peak period for congestion reduction purposes nearly every weekday, it will be more predictable to drivers if it is opened at the same time every weekday (such as 7 a~~.~~m~~.~~) rather than different times based on minor variations in traffic from day to day. In this case, the benefits of dynamic over static part-time shoulder use would still be realized by the ability to extend the operating hours if high traffic volume was still present at the end of the typical a~~.~~m~~.~~ peak period or occasionally open the shoulder at other times such as weekends.

12.8.5 Automated Enforcement

The current methodology of Ontario enforcement is based on a manual approach by visual inspection by patrol officers to the vehicles using the HOV lane. -Manual enforcement is labor-intensive, costly, and sometimes has negative safety implications. -With the emerging shift from HOV to HOT (high-occupancy toll) lanes, enforcement becomes more complex, because vehicles can be in the lanes legally either by meeting an occupancy requirement or by paying the electronically charged toll.

Several studies were conducted to explore the feasibility of using new technologies/techniques to improve the effectiveness of violation enforcement and to evaluate the capability of a novel image sensor device to automate detection of in-vehicle occupants to flag law enforcement of HOV/HOT lane violators. -Experiments were conducted to determine this capability across varied conditions and scenarios to assess detection segmentation algorithms of vehicle passengers and drivers. -Although occupancy detection through vehicle glass could be achieved in many cases, improvements were suggested to be made to such a detection system to increase robustness and reliability as a law enforcement tool. –Other studies were completed on automated occupancy enforcement using roadside infrared systems. -It is a costly technique and could produce image only front-seat passengers.

HOT lanes networks would likely require at least 2-person occupancy for zero or reduced-rate tolls. The in-vehicle detection approaches would rely on using data from airbag deployment systems. Those systems are required and being planned only for front seats, and there are legal and policy reasons making it unlikely that such data can be transmitted from the vehicle to use for enforcement purposes.

Both roadside and in-vehicle occupancy verification systems raise serious privacy concerns. Declaration transponders could be a more promising approaches, but still relies on patrol officer enforcement.

Other alternative approach relies on two policy changes—transponders for all HOT lane users and registered carpools, to simplify the occupancy verification and enforcement problem for HOT lanes. -It aims to reduce enforcement requirement to the same used for electronic toll collection, by requiring all eligible carpools to be registered and have transponders. The toll collection software would be written to charge the zero or reduced-rate toll to vehicles identified as registered carpools when their transponder is detected in the lanes during peak periods.

12.9 Illumination

The Ontario policy for highway illumination Directive **(PLNG-B-05)** specifies the warrants for Continuous / Full illumination of provincial highways.

As with any other freeway element, safety of operation is essential for an HOV lane. Particularly with barrier-separated facilities, the use of lighting at access and egress locations is desirable to help drivers at night to identify and navigate these areas of weaving traffic. Therefore, partial lighting of these areas is warranted when continuous highway lighting is not warranted.

The presence of lighting in corridors where Closed-Circuit Television monitoring is used as an element in a Freeway Traffic Management System aids in monitoring and in incident management.

The most significant HOV-related illumination requirement is the provision of adequate lighting in enforcement areas to allow monitoring of vehicles occupancies (recognizing that peak periods during the winter months occur during darkness in Ontario). -HOV ramp meter bypass lanes and HOV lane access zone, are key locations in this regard.

Partial Illumination

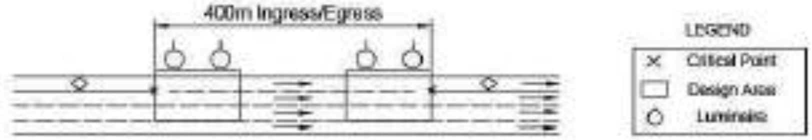
In general, where continuous lighting is not warranted on provincial highways, partial lighting of HOV/HOT ingress and egress zones is required.

A minimum of two lights are required at each end of the HOV/HOT ingress and egress zone.- If HOV/HOT ingress zone and egress zone are separated, additional lights may be required as follows.– HOV/HOT ingress and egress zones should be lighted to the same minimum maintained lighting levels as specified in the MTO Electrical Engineering Manual for other partial lighting applications.

The selection of the partial lighting pole location should be coordinated with the placement of managed lane tolling system ~~and also~~and coordinated with the placement of static signs and typical Intelligent Transportation System (ITS) elements.

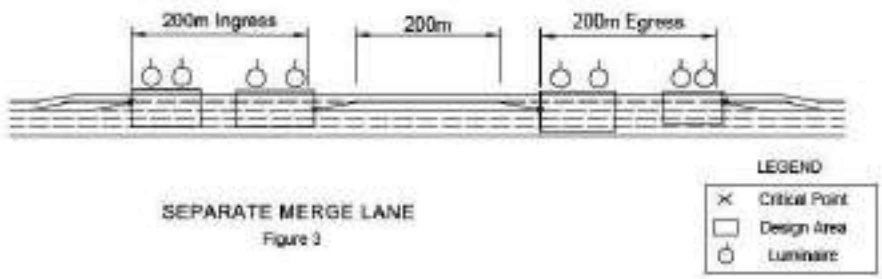
Note: distances in the following **Exhibit 12CF**~~**Figures 12.9.1**~~ and ~~**12.9.2**~~**Exhibit 12CG** are for illustration purposes only and may vary per location. -The figures show lighting poles in the median (preferred), alternatively the lighting poles may be placed on the outside of the highway, rather than the median, provided that the required lighting levels are achieved.

Exhibit 12CF
Illumination of Managed Lanes

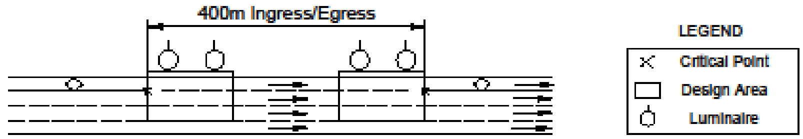


COMBINED WEAVE ZONE
Figure 1

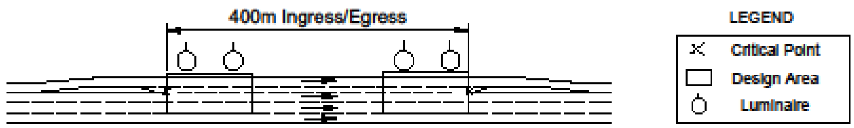
COMBINED WEAVE LANE
Figure 2



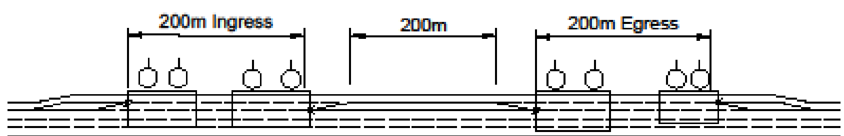
SEPARATE MERGE LANE
Figure 3



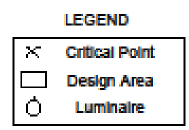
COMBINED WEAVE ZONE
Figure 1

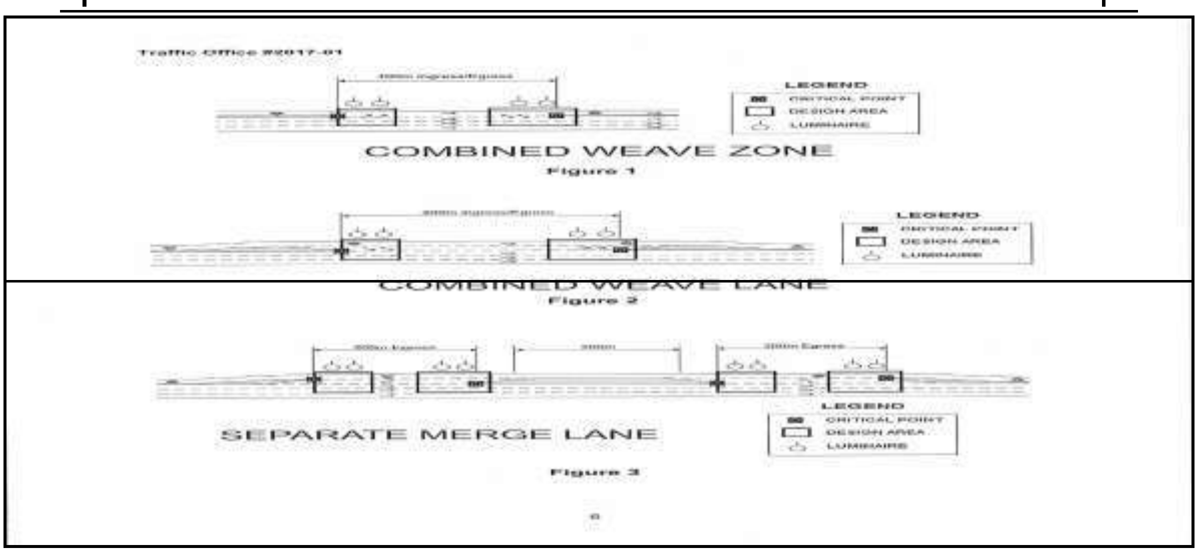


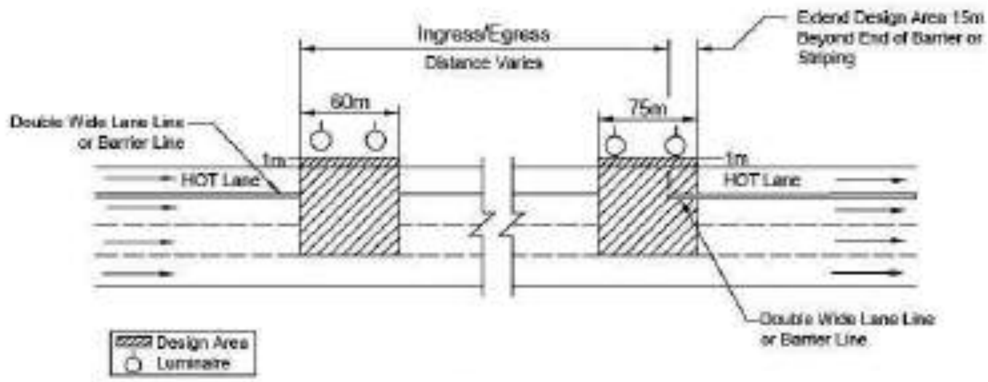
COMBINED WEAVE LANE
Figure 2



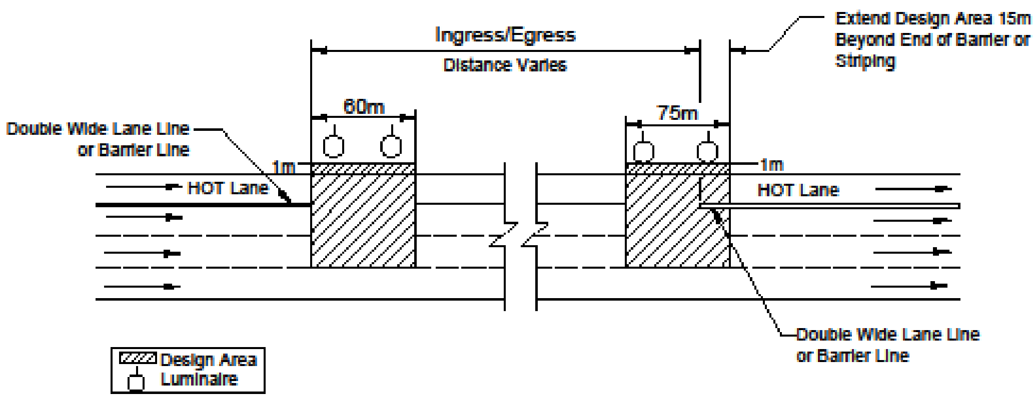
SEPARATE MERGE LANE
Figure 3



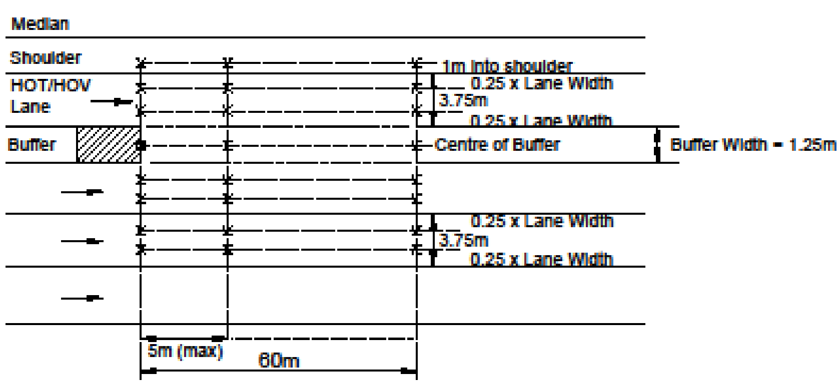




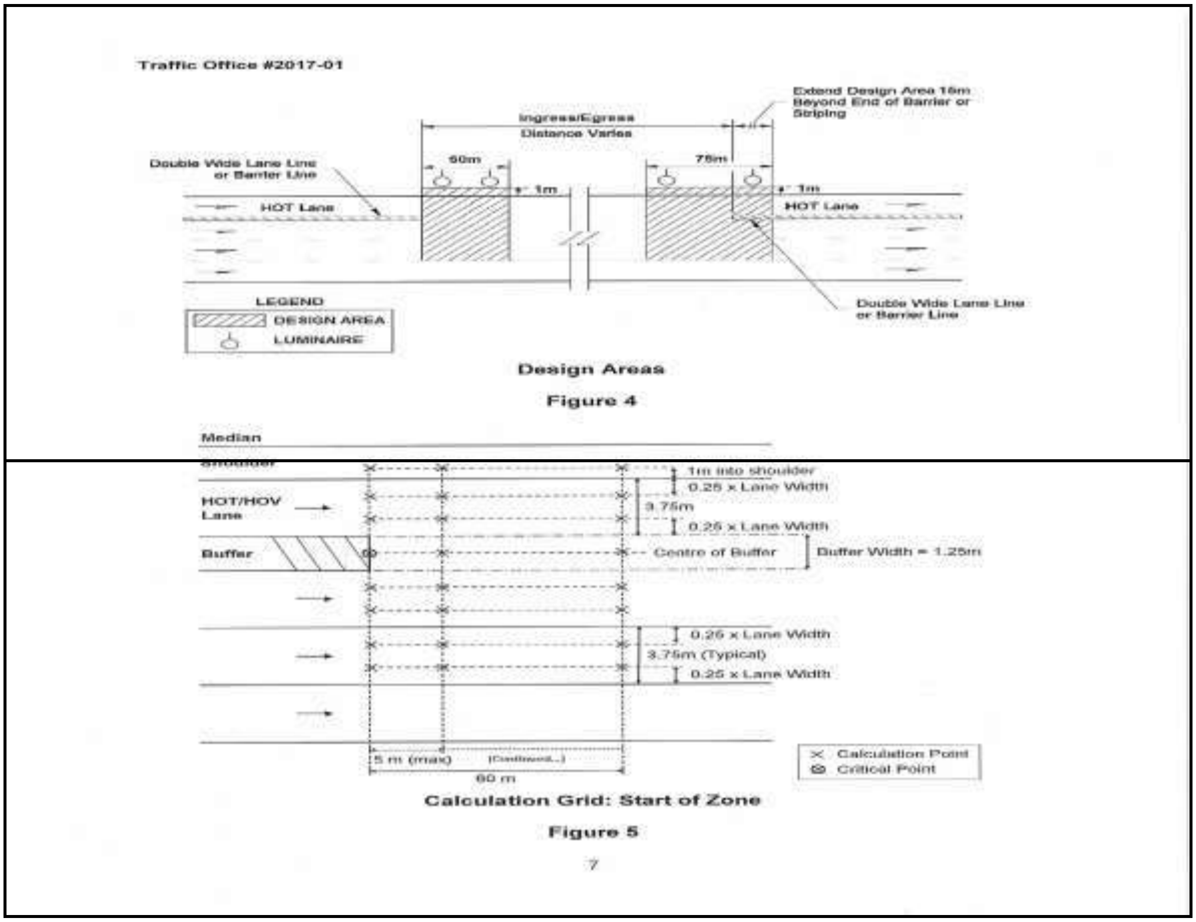
Design Area
Figure 4



Design Area
Figure 4



Calculation Grid: Start of Zone
Figure 5



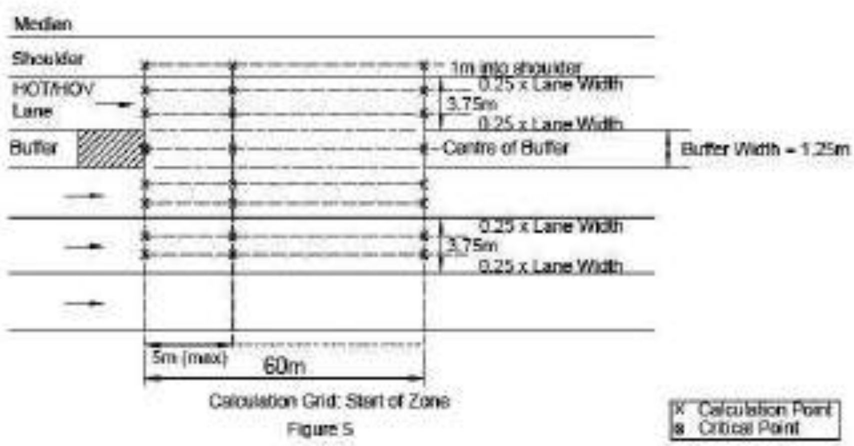
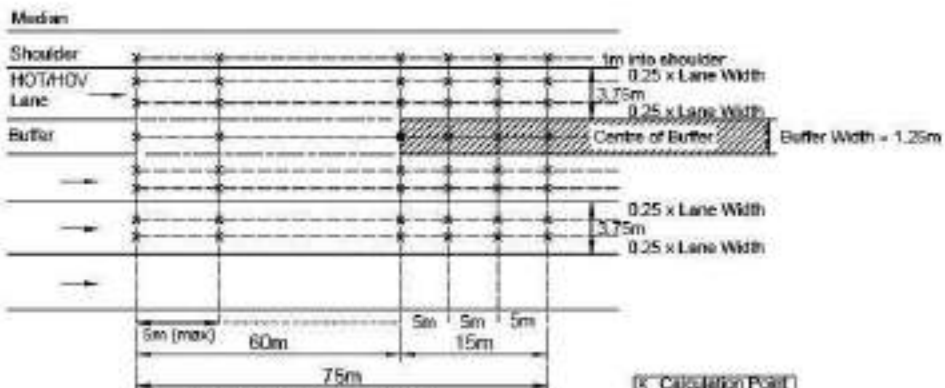


Exhibit 12CG

Design Areas for Illumination of Managed Lanes

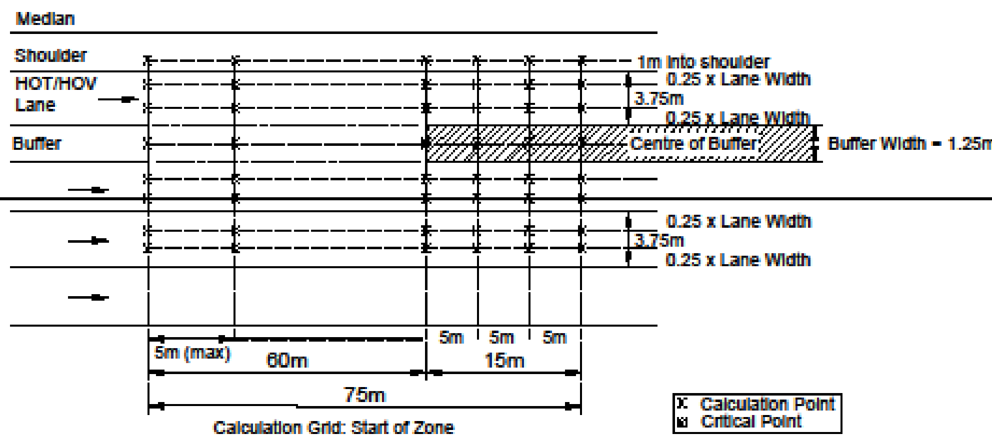
Source: CR, Provincial Engineering Memorandum Traffic Office #2017-01, April 2017 (Appendix A)

~~**Figure 12.9.1 Illumination of Managed Lanes**~~



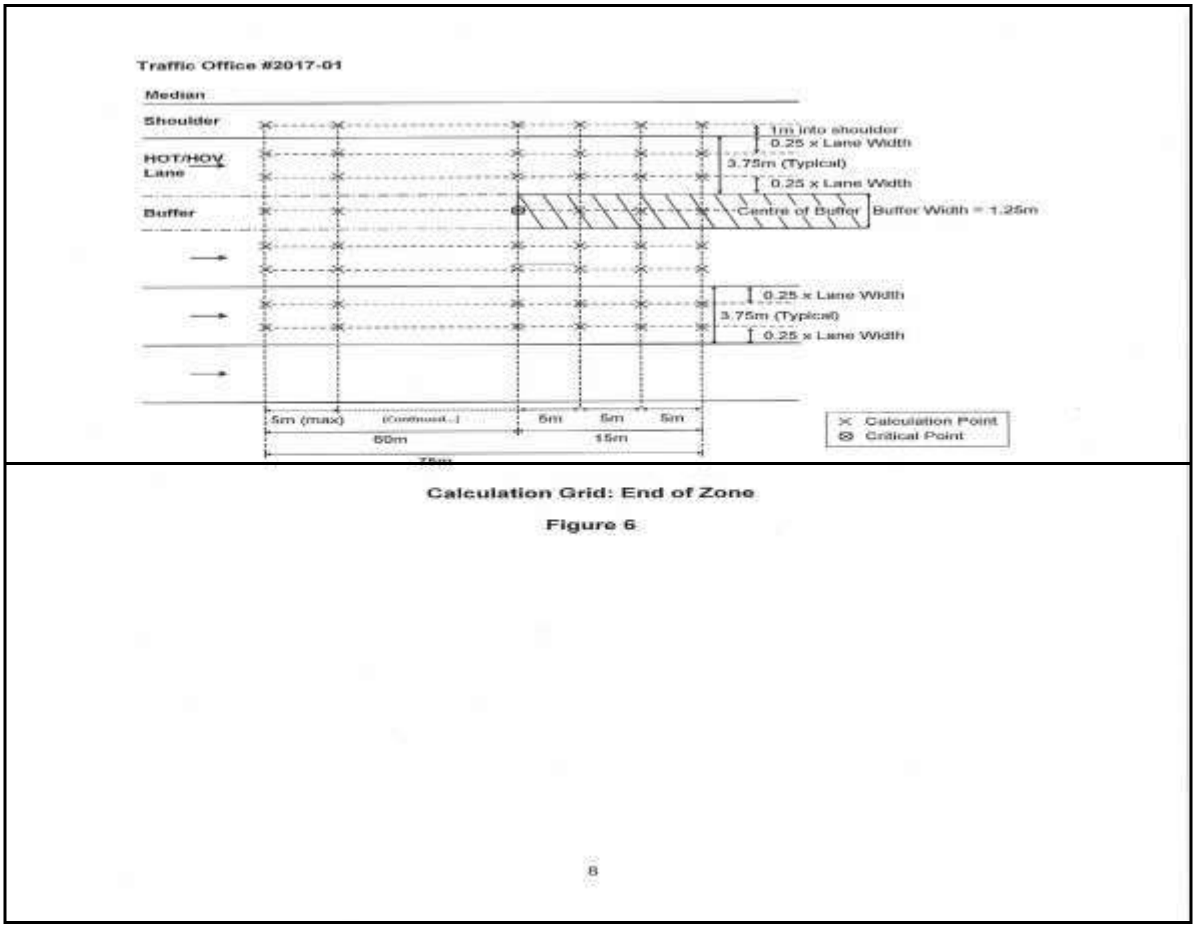
Calculation Grid: Start of Zone

Figure 6



Calculation Grid: Start of Zone

Figure 6



~~**Figure 12.9.2 Design Areas for Illumination of Managed Lanes**~~

~~*Source: CR, Provincial Engineering Memorandum Traffic Office #2017-01, April 2017 (Appendix A)*~~

12.10 Maintenance

The ability to carry out regular freeway maintenance activities in a matter which ensures the safety of maintenance crews and minimizes disruption to traffic flow should not be affected by the presence of an HOV facility. -Some HOV designs have inherent additional operational costs; the daily placement of barriers or pylons on contraflow lanes, for example, or the shifting of barriers to allow reversible operation.

The presence of adequate shoulders, use of advance signage (including Chan~~r~~geable Message Signs), and restriction of activities to off-peak periods are typical effective strategies.

In Ontario, the removal of snow from the freeway system is a crucial maintenance activity; in this respect, concurrent flow non-barrier-separated facility design is favoured over barrier-separated lanes. -In the presence of barriers, the consideration of the reduction of shoulder width in constrained areas from a standard 2.5 - 3.0 m should ~~take into account~~consider snowploughing and snow storage needs.- The use of a reduced shoulder for an extended length is highly undesirable and should only be considered if an acceptable snow removal strategy can be applied.

Assigning a high priority to HOV lanes for both snow removal and litter removal is desirable, given that the lanes rely on smooth peak period operation to carry a disproportionate share of freeway users.

In the long term, HOV lane pavement resurfacing, or reconstruction can be a significant challenge; again, non-barrier-separated lanes are more flexible, in that the adjacent freeway lane can be designated for HOV use on a temporary basis during the construction period.- If the work can be accomplished on a weekend (in the nearly three days between the Friday and Monday peak period peak direction flows) it would be desirable to do so, and to limit the impact on peak period peak direction weekday HOV flow.

For reversible lanes, and ~~in~~ particularly those with heavy volumes of buses, wheel rutting in the single lane can develop over time to create a problem, especially when combined with ~~snowplowing~~snowploughing and reconstruction constraints as cited above. -The pavement of such a facility should be designed for strength and longevity.

Since HOV lanes are located in either the median or right-side lanes, maintenance of a clear path for surface water drainage across the lane is essential; in the case of barrier-separated lanes, drainage slots in the base of the barrier are required.

Maintenance of lanes designated for part-time shoulder use is similar to maintenance of general-purpose lanes. It is beneficial to keep part-time shoulder at the same level as general-purpose lanes. -Conducting maintenance on part-time shoulder use segments that requires maintenance vehicles to stop on the shoulder will need to be conducted at times the shoulder is closed to traffic. On high volume freeways where, part-time shoulder use is most commonly used, there may already be restrictions on maintenance during peak period when the shoulder lane would be open.

After snowfall, part-time shoulder use is typically plowed after all general-purpose lanes on the freeway have been plowed. This creates the potential for the shoulder to be closed during a period when it is scheduled to be open, although this ~~usually~~ typically has little effect on traffic operations due to reduced traffic volume during snow. It is beneficial to open the dynamic part-time shoulder use segment throughout the duration of a snowstorm because vehicles driving in the shoulder help to distribute salt that has been spread there.

Maintenance of toll equipment, software, traffic sensing, and related toll enforcement systems for priced managed lanes requires specialized attention, which may be specific in nature to the technology deployed by the tolling integrator and systems vendor for each facility. This technology may also be employed in other lanes of the roadway. Maintenance on toll collection equipment is ~~usually~~ typically conducted at night during periods of low utilization when lanes can be closed. These tightly integrated systems require a high level of reliability and preventative maintenance. Performing preventative maintenance helps avoid unforeseen equipment outages. Every attempt should be made to provide maintenance access off the roadway to equipment cabinets so that access to devices does not requir~~e~~ ~~ing~~ lane closures.

12.11 Transit Facilities

The provision of transit stations where passengers and/or buses may gain access to the managed lanes is essential in corridors where transit service forms a significant element of the managed lanes user market. -Location of Transit Facilities stations along managed lanes help improve transit ridership and improve the productivity of the lanes in terms of passengers or passenger kilometers of travel carried. -Such facilities may be as simple as a bus bay and shelter on a right side HOV lane or as complex as a multi-level multimodal transportation gateway astride the freeway. -The standards for transit stations in the managed lanes context are still evolving, and in any case will tend to be site-specific and not readily standardized in application.

The design of online and offline bus stations along managed lanes should consider the following:

1. Locating stations adjacent to major activity concentrations, park-and-ride facilities, and interchanging bus lanes.
2. Maintaining the speed, reliability, and safety of the managed lanes by providing adequate spacing between stops, acceleration and deceleration lanes, and separate lanes for buses entering, exiting, and stopping at stations.
3. Providing adequate station platform capacity that conforms to Accessibility for Ontarians with Disabilities Act and its standards.

The Transit way can have one of three forms:

- **Median Busway:** A dedicated bus facility in the median area, ~~usually~~ typically separated physically from other forms of traffic and with free-flow ramps to and from other types of BRT running ways ~~**(Figure 12.11.3)**~~.

- **HOV/HOT Lanes:** A running way shared with high-occupancy vehicles on either the median side or the outer lanes of the freeway and not necessarily separated physically from the general traffic lanes.
- **Shoulder:** Permitted use of the outside shoulder of the general traffic lanes by Transit vehicles. Sometimes limited to peak hour periods or congested conditions and ~~usually~~ typically with various operating constraints, such as maximum operating speed.

Exhibit 12CH

Freeway HOV Lane (Highway 403, Mississauga, ON)

~~**Figure 12.11.1 Freeway HOV Lane (Highway 403, Mississauga, ON)**~~

~~**Figure 12.11.2 Bus on Freeway Shoulder (Ottawa, ON)**~~

~~**Figure 12.11.3 Freeway Median Busway (Interstate 45, Huston, Texas)**~~

HOT lanes represent a new opportunity for transit agencies with many potential benefits, including increased funding, faster travel speeds, more riders, and greater community visibility. However, these benefits do not emerge automatically. Transit agencies need to work closely with HOT lane developers to realize these positive externalities and avoid negative ones, such as access conflicts, increased traffic congestion, and ridership losses.

The Transit Facility location can also be Off-Line / Interchange

- I~~i~~nterface at Parclo A interchanges
- Transitway stations
- Park and Ride lots

12.11.1 On-Line Stations

One of the most difficult tasks facing the planner of a managed lane facility is to reconcile its inherent tendency to be more beneficially located in the freeway median with the need for excellent transit vehicle and passenger access through interface with crossing roads. The goal is to allow express (through) buses to use the managed lane without having to divert offline to pick up passengers, and for local transit users to gain direct access to the lanes without having to weave across congested mixed flow traffic.

The optimum solution may be to provide a transit station, elevated (or depressed) at the cross-street level, with direct managed lane access / egress ramps. There are two fundamental drawbacks, however:- the physical requirements of such a facility (if feasible) are significant, leading to high cost and potentially enormous retrofitting problems; and a passenger interface in the middle of a freeway presents a generally hostile environment to the passenger, particularly for the desired walk-in movement from surrounding development, for example in winter conditions. -Such a facility may also be unable to address the Park and Ride or Park and Pool components of the managed lane market.

Center island platforms are used to minimize platform space since both directions share a common area for patrons that are removed as much as possible from freeway operations. They require only one set of vertical pedestrian access points. Because doors on buses are ~~usually~~ on the right-hand side, the center platforms require channelized crossovers on each end for bus drivers to negotiate.

Offline stations are sometimes provided to serve as collection and distribution points (e.g., transit centers, intermodal centers, and/or parking facilities) that are located near the managed lanes. The stations can be incorporated into other land uses as part of parking facility design. Access to and from the managed lanes is either along local street connections or via direct ramps. The station may be somewhat removed from the freeway corridor, or the station may be adjacent to the freeway right-of-way. Offline transit stations often provide connections to a parking facility and rely on the local street network.

Some examples of median on-line HOV transit stations exist and many concepts have been developed for such facilities but in the Ontario context it must be considered an unlikely scenario for actual application except possibly for local-express passenger transfer in a non-retrofit situation.- **Exhibit 12CI**~~**Figure 12.11.4**~~ illustrates a typical median online HOV transit station.

The provision of bus bays on right side HOV lanes exhibits significantly greater potential for utility, reasonable cost, and attractiveness (and indeed the potential for good local transit interface is a significant portion of the rationale for right side lane application. -See **Exhibit 12CJ**~~**Figure 12.11.5**~~.

Right side HOV lane bus bays are suited to locations between interchanges, at simple crossing structures, or at major employment of residential focal points for simplicity of access and operation; if an interface is needed at an interchange, the operational and physical requirements alter so significantly as to require special consideration, and a simple bus bay is generally not feasible.

There may be some situations where it is desirable to link the busway with a crossing or adjacent high-standard roadway or controlled access highway. Conventional one-way or two-way ramps are used. -Single-lane ramps should have a minimum width of 4.2 m (14 feet) with 1.2 m (4-foot) shoulders to allow for passing of disabled buses or maintenance vehicles. For radii of 120 m (500 feet) or less, off-tracking of a bus becomes significant and should be determined to verify the minimum width needed for passing. Multiple lane ramps should have lane widths consistent with the adjacent sections of the busway.

The median busway should be designed with at least a 0.6 m (2-foot) paved shy distance between the edge of the median barrier and the edge of the bus lane. The bus lane should be at least 3.2 m (10.5 feet) wide, with a preferred width of 3.6 m (12 feet). The median busway does not require a horizontal separation between the bus lane and the adjacent general-purpose traffic lane, although 0.6 m (2 feet) of painted marking separation is considered desirable unless speed differential regulation applies in which case greater separation may be required.

The unobstructed vertical clearance over the busway should desirably be a minimum of 5.0 m (16.5 feet). The minimum recommended clearance is 4.7 m (15.5 feet). This will allow other vehicles, such as maintenance and emergency vehicles, to utilize the busway, as well as allow for possible future conversion to light-rail transit.

12.11. 2 Off-Line / Interchange Interfaces

Most of the users of a freeway HOV facility will access the freeway corridor from the crossing arterial road system, and most major arterials have interchanges with the freeway. -The need to transfer passengers to the HOV express services, for local buses to access the HOV lane, and for mixed flow traffic to use the interchange ramps efficiently and safely all conflict at the typical Ontario Parclo "A" type interchange. –Significant constraints are placed on the median interface concept and bus bays for right side HOV lanes are most appropriately located in mid-interchange positions.

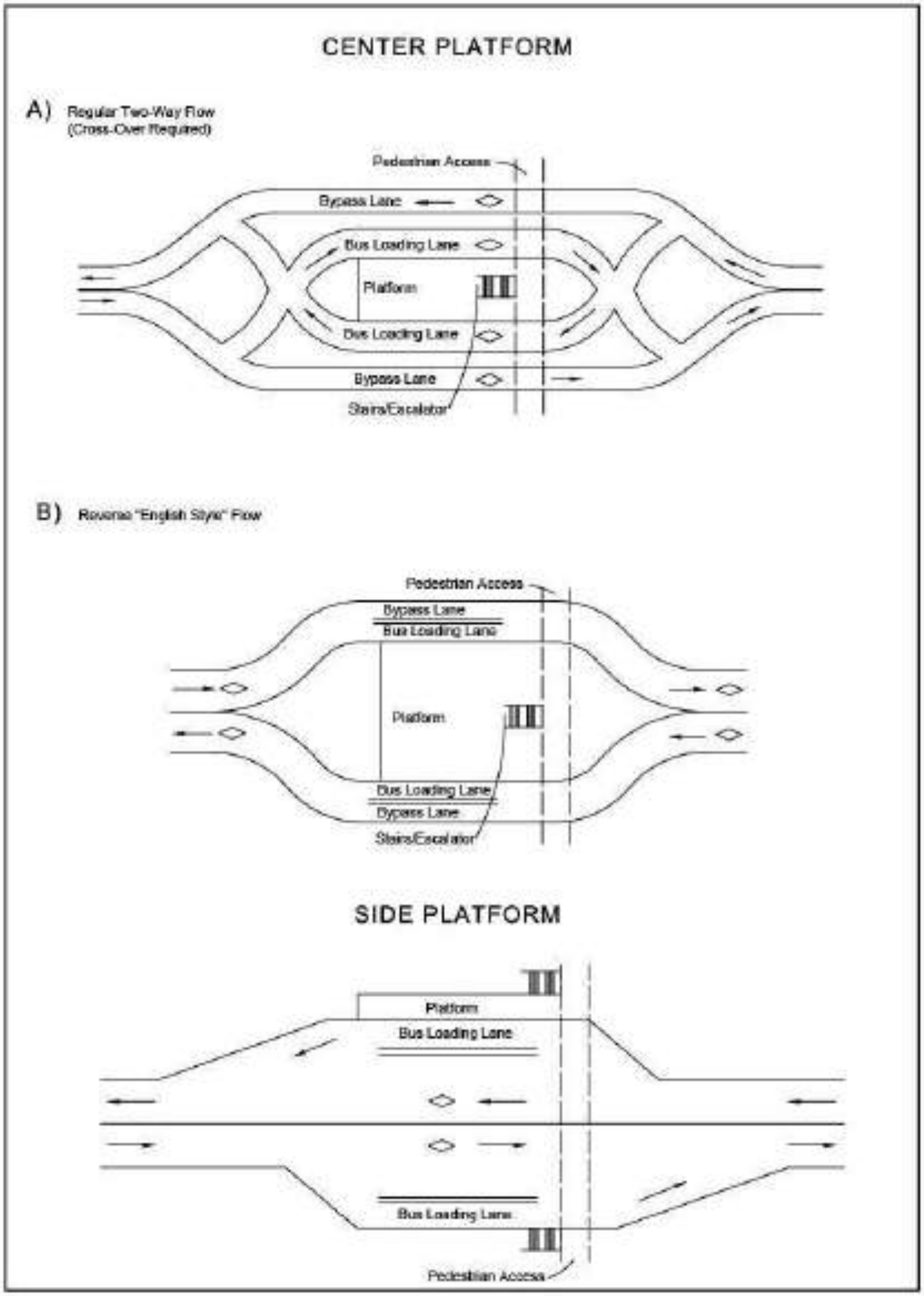
The most common alternative, and one which is essentially impossible to use by median HOV lane express buses, is the provision of bus interface opportunities at the ramps of Parclo "A" interchanges. -At Parclo "A" type interchanges, the stopping of local buses on the crossroad within the interchange area poses unacceptable safety and operational impacts.

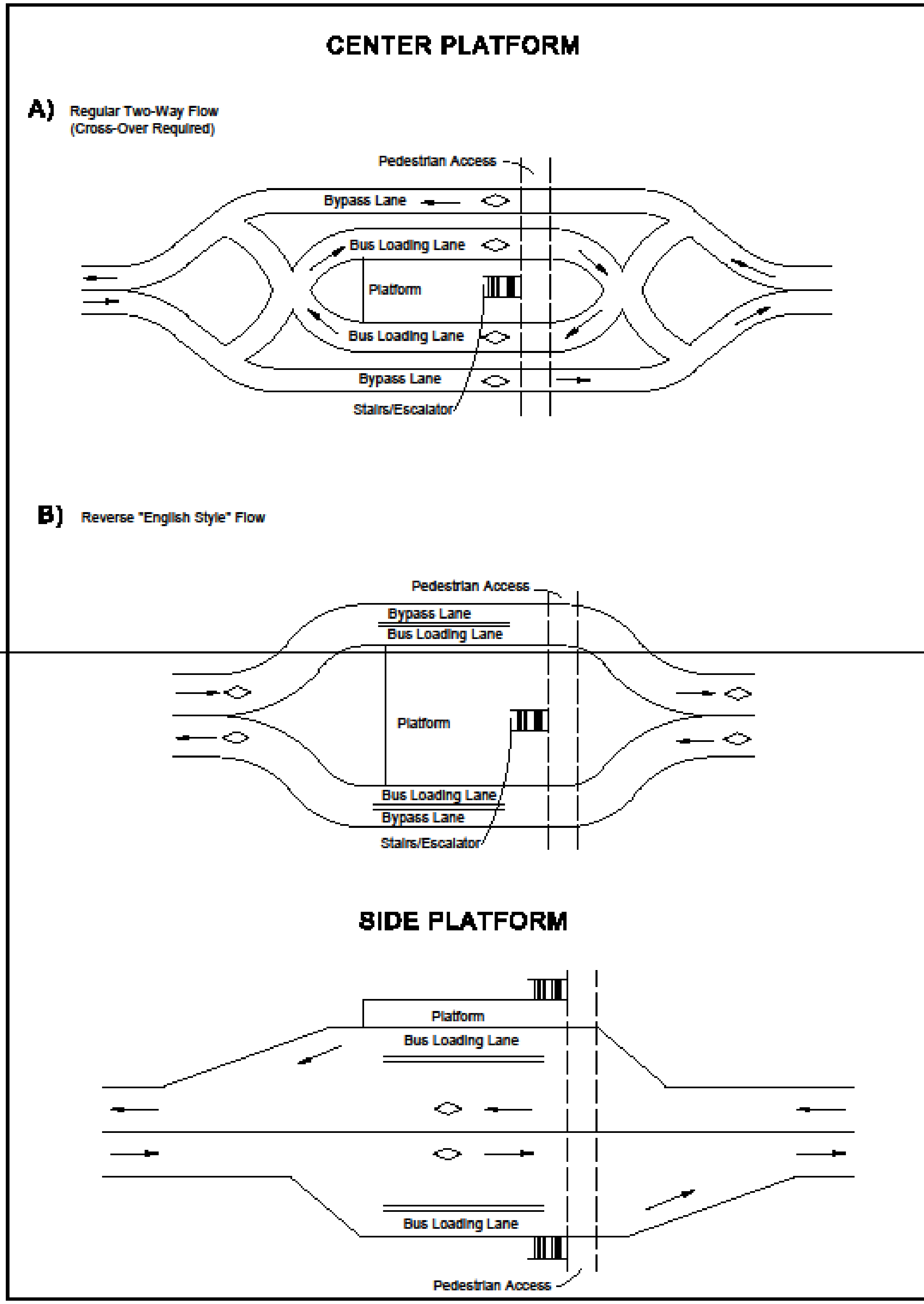
Configurations for three interface types are shown in **Exhibit 12CK**~~**Figures 12.11.6**~~**, Exhibit 12CL**~~**12.11.7**~~ and **Exhibit 12CM.**~~**12.11.8**~~ Standards have yet to be developed for "B" type interchanges or other variations found on the Ontario freeway system. -It should be noted that such interfaces are well suited to interchanges with ramp metering and accompanying HOV Bypass Lanes, although there are some implications as to the location of the bypass lane (e.g. on the left side of a metered entry ramp for a Parclo "A" layout) and for property requirements. The design standards are already applied on new Ontario freeways in urban areas with respect to property acquisition needs.

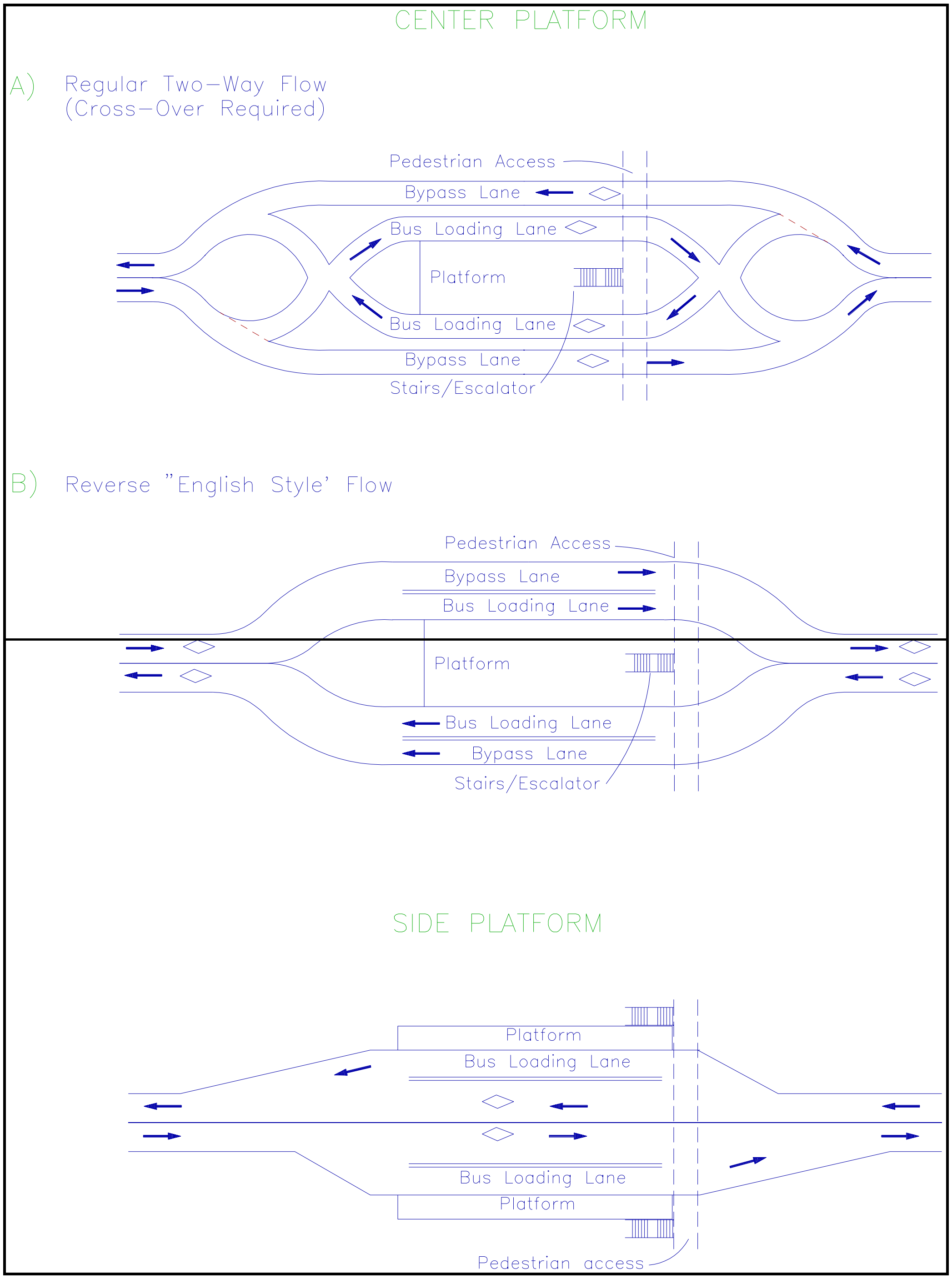
An interchange type which is well suited to off-line transit interface is the full diamond layout, however, such configurations are rare in Ontario.- If a new freeway is being planned with HOV priority in mind, traffic patterns at each interchange should be examined closely to determine the need for a "Parclo A" type interchange and the traffic signal impact if one or both of the inner loops were to be replaced by left turns or other substitutes. -If less than 100 vehicles in the peak hour are projected to use the loop ramp, it may be possible to accommodate those vehicles by a left turn at the off-ramp terminal signal, thereby freeing up significant flexibility for HOV interface options, as well as property which could be used for a Park and Ride lot or transit facility. -There may be retrofit opportunities at some interchanges in proposed HOV corridors.

Rather than attempting to accommodate all of these conflicting demands at a Parclo "A" interchange (which is a complex enough operating entity as it is), it may be more appropriate to group Park and Ride, Park and Pool, local-express transit interface, and walk-in transit facilities all in a single dedicated off-line station linked with the HOV lane, either by direct ramp to the adjacent freeway median or by slip ramp to / from a right-side facility. -The provision of a direct ramp requires cost-effectiveness justification in the form of significant demand levels (provided by the large multi-purpose HOV lot). -It may be considered that a transit interface facility as shown in **Exhibit 12CL**~~**Figure 12.11.7**~~ is capable only of accommodating walk-in and transfer passengers from the arterial route; the Park and Ride market and Park and Pool HOV formation would still have to be addressed in other ways. -Under these circumstances, the provision of a dedicated multi-purpose HOV centre at key points in an HOV lane corridor should be seriously considered as significant ancillary features to the HOV lanes themselves.

Exhibit 12CI
Median On-Line Transit Station


CENTER PLATFORM
A) Regular Two-Way Flow
(Cross-Over Required)
Pedestrian Access
Bypass Lane
Bus Loading Lane
Platform
Bus Loading Lane
Bypass Lane
Stairs/Escalator
B) Reverse "English Style" Flow
Pedestrian Access
Bypass Lane
Bus Loading Lane
Platform
Bus Loading Lane
Bypass Lane
Stairs/Escalator
SIDE PLATFORM
Platform
Bus Loading Lane
Bus Loading Lane
Pedestrian Access

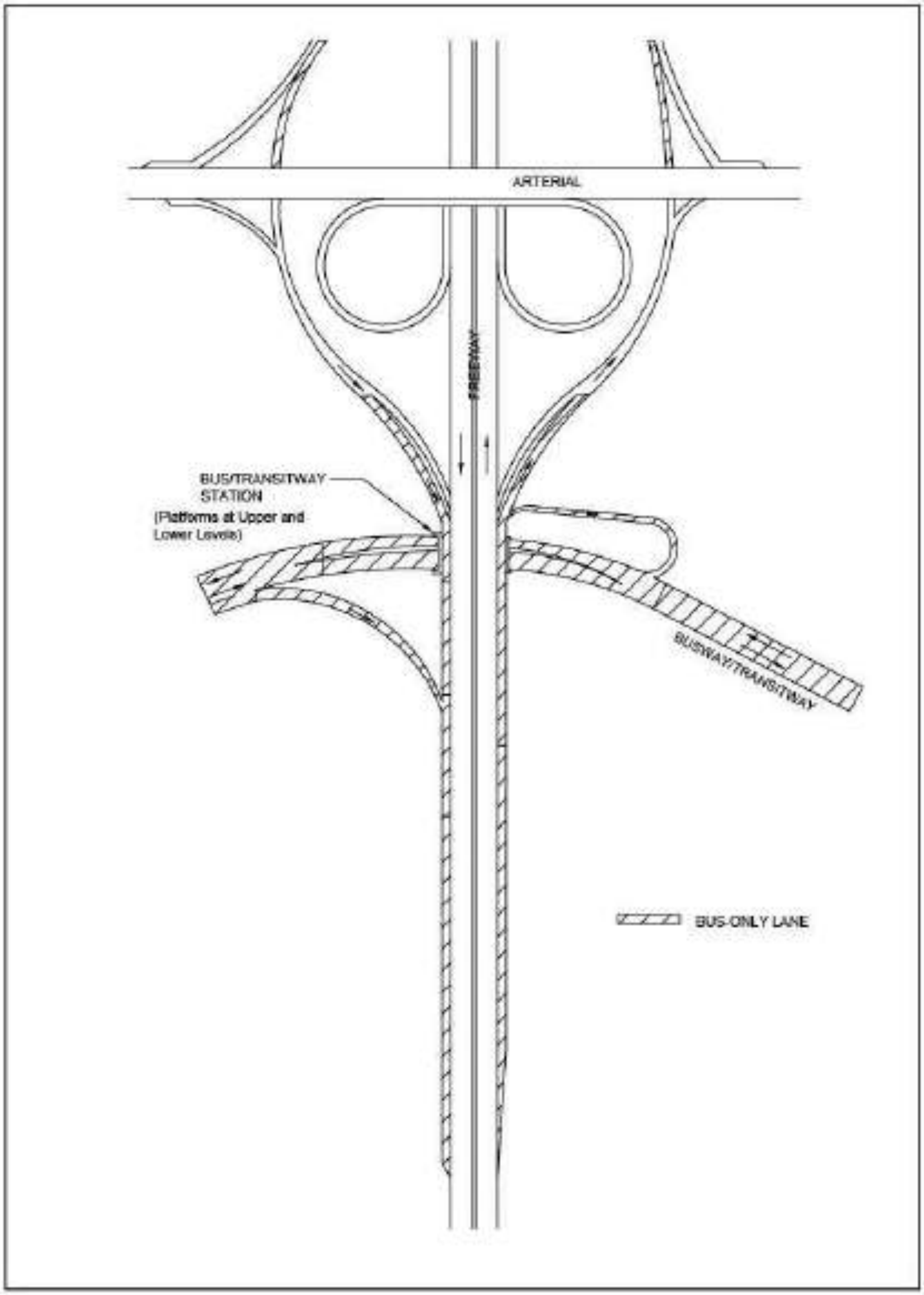

CENTER PLATFORM
A) Regular Two-Way Flow
(Cross-Over Required)
Pedestrian Access
Bypass Lane
Bus Loading Lane
Platform
Bus Loading Lane
Bypass Lane
Stairs/Escalator
B) Reverse "English Style" Flow
Pedestrian Access
Bypass Lane
Bus Loading Lane
Platform
Bus Loading Lane
Bypass Lane
Stairs/Escalator
SIDE PLATFORM
Platform
Bus Loading Lane
Bus Loading Lane
Pedestrian Access

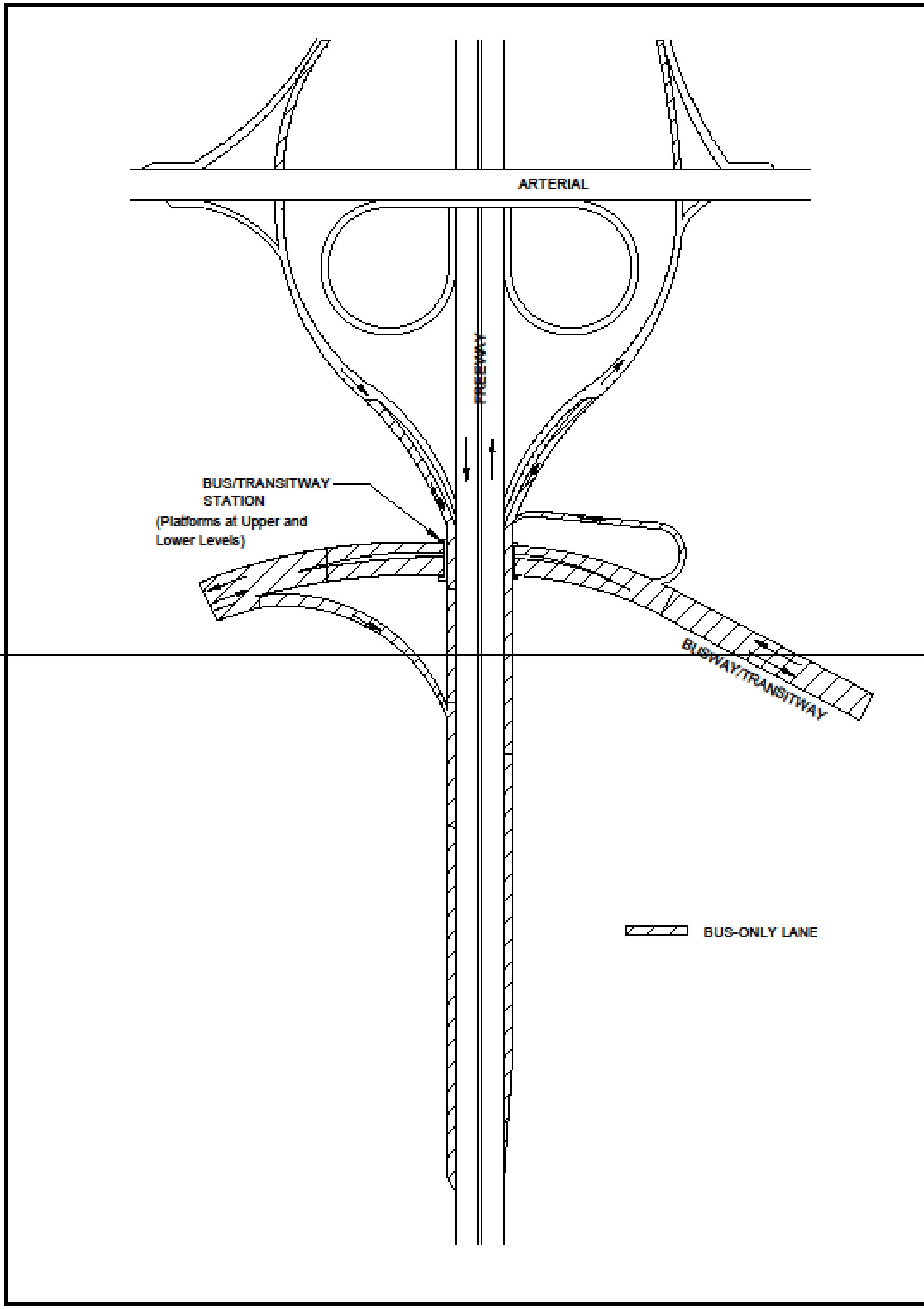


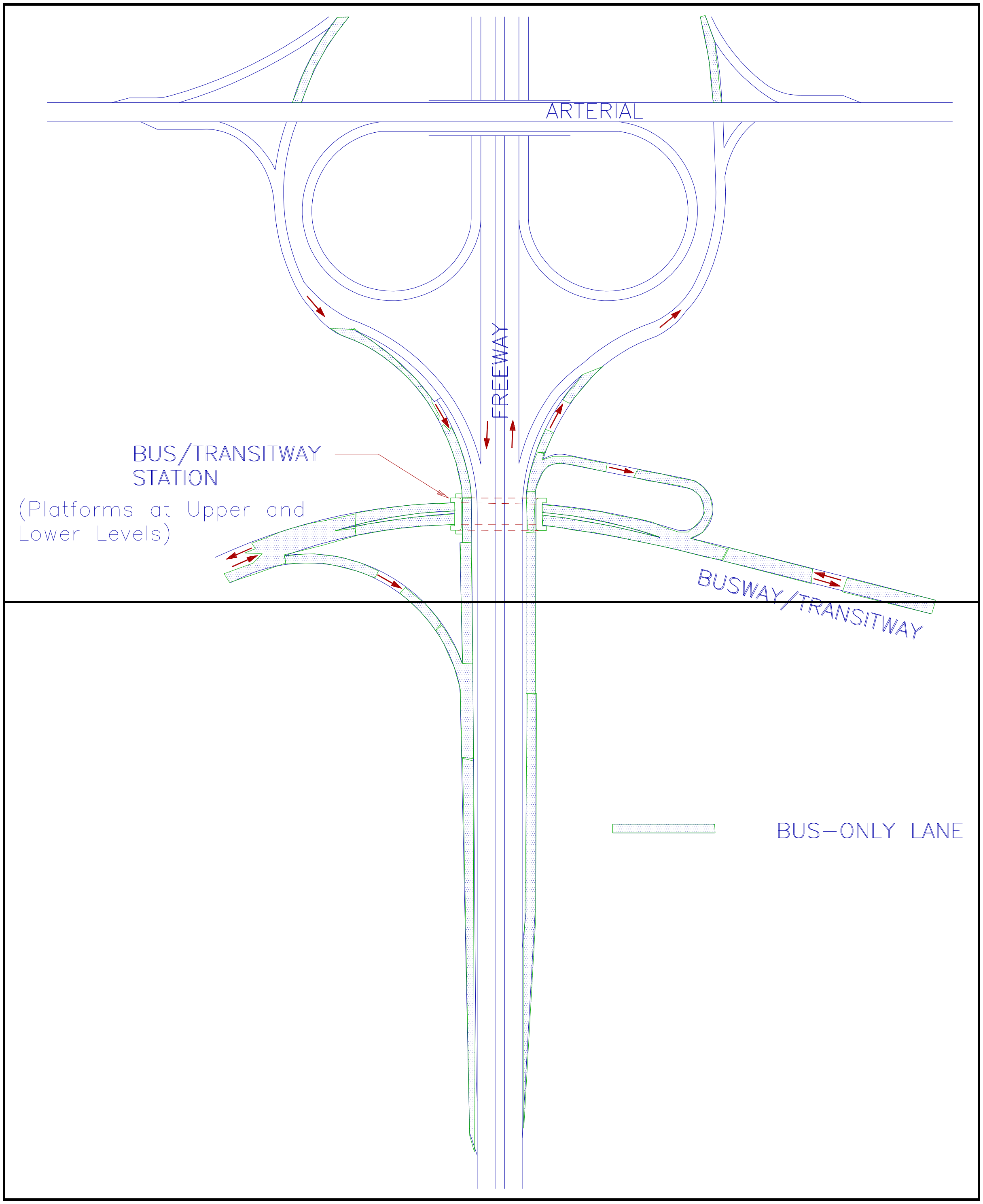
~~**Figure 12.11.4 Median On-Line Transit Station**~~

Exhibit 12CJ

On-Line Transit Stop for Right Side RBL


ARTERIAL
FREEWAY
BUS/TRANSITWAY STATION
(Platforms at Upper and Lower Levels)
BUSWAY/TRANSITWAY
BUS-ONLY LANE

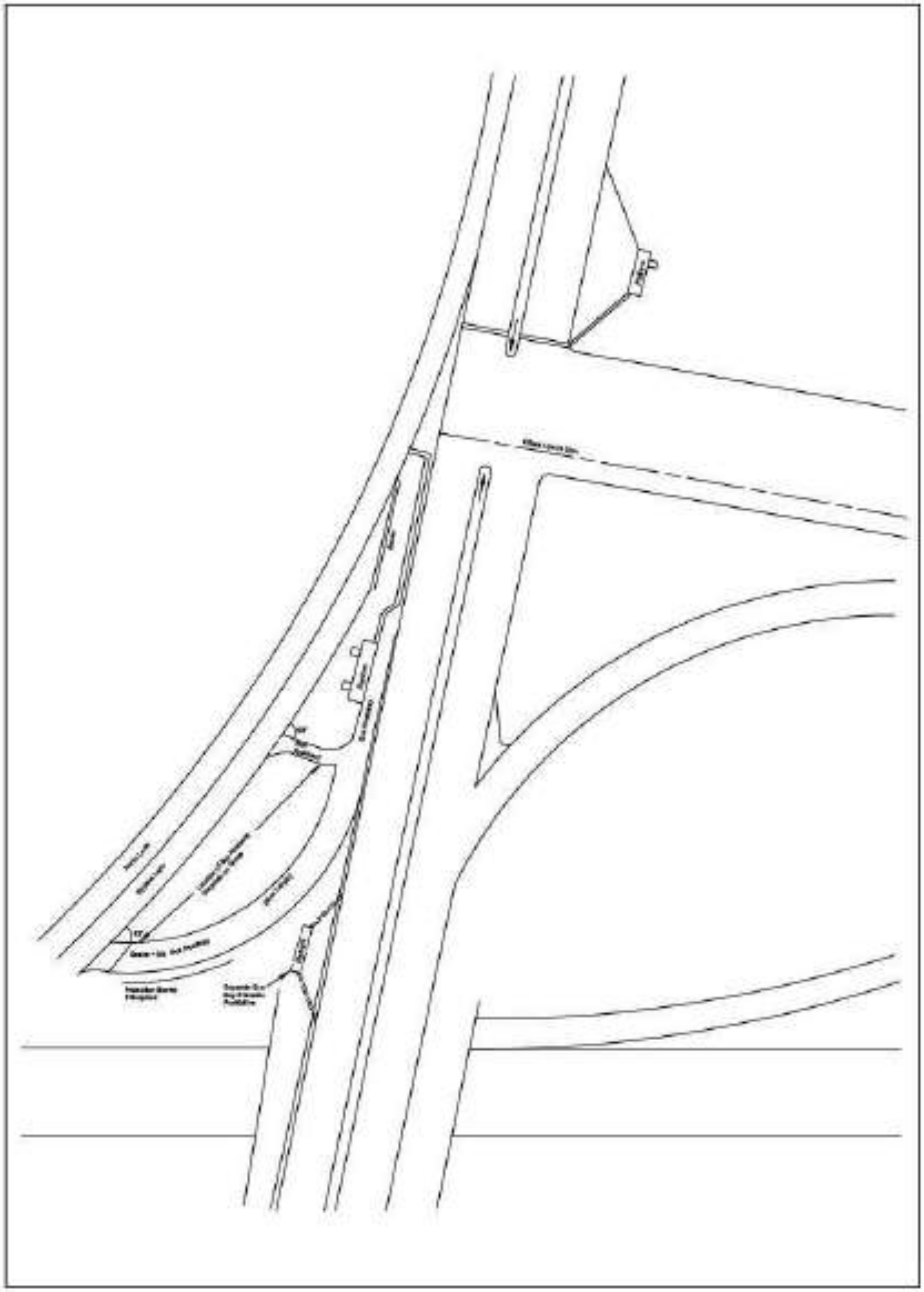

ARTERIAL
FREEWAY
BUS/TRANSITWAY STATION
(Platforms at Upper and Lower Levels)
BUSWAY/TRANSITWAY
BUS-ONLY LANE

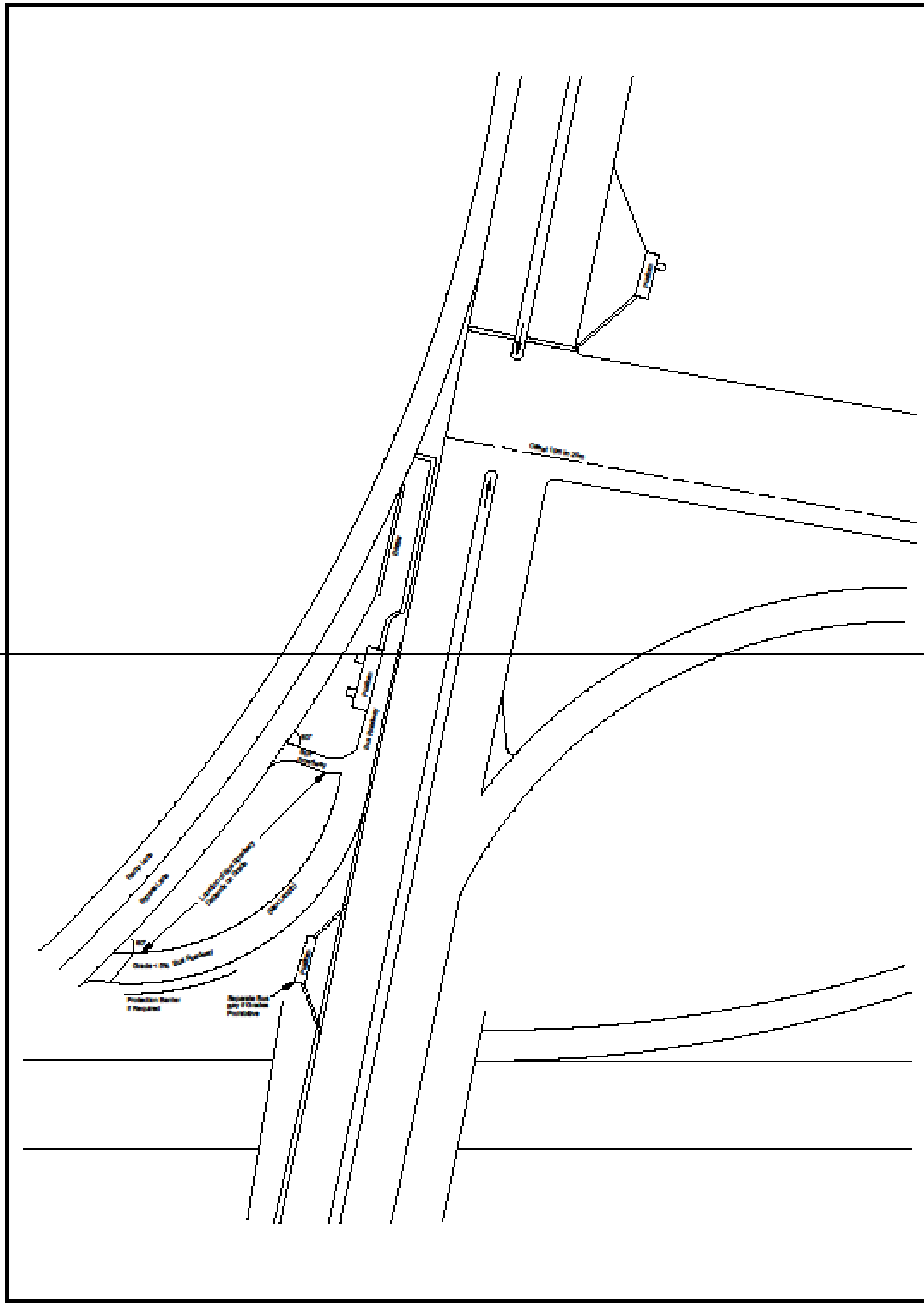


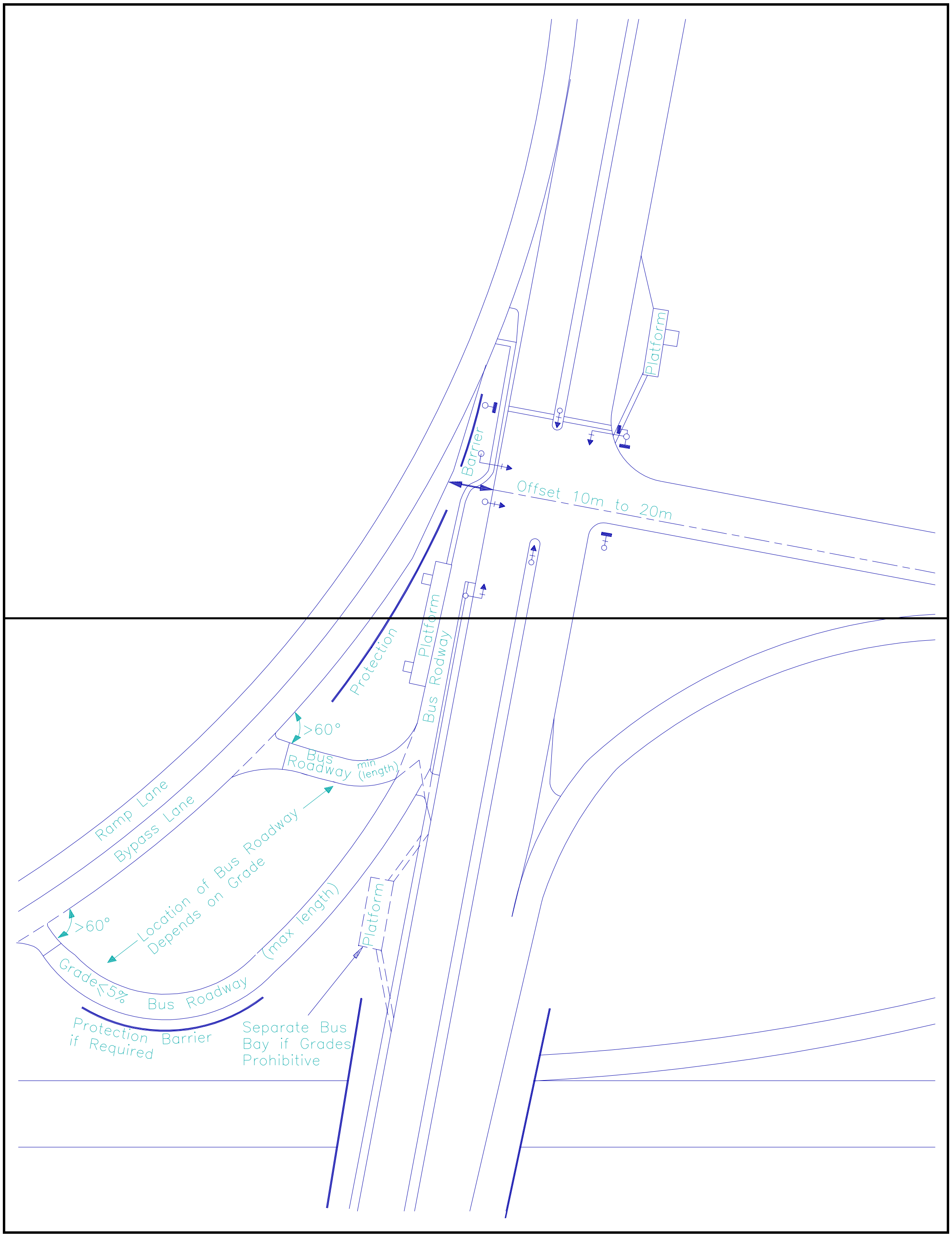
~~**Figure 12.11.5 On-Line Transit Stop for Right Side RBL**~~

Exhibit 12CK

Freeway Interchange Bus Interface TYPE I



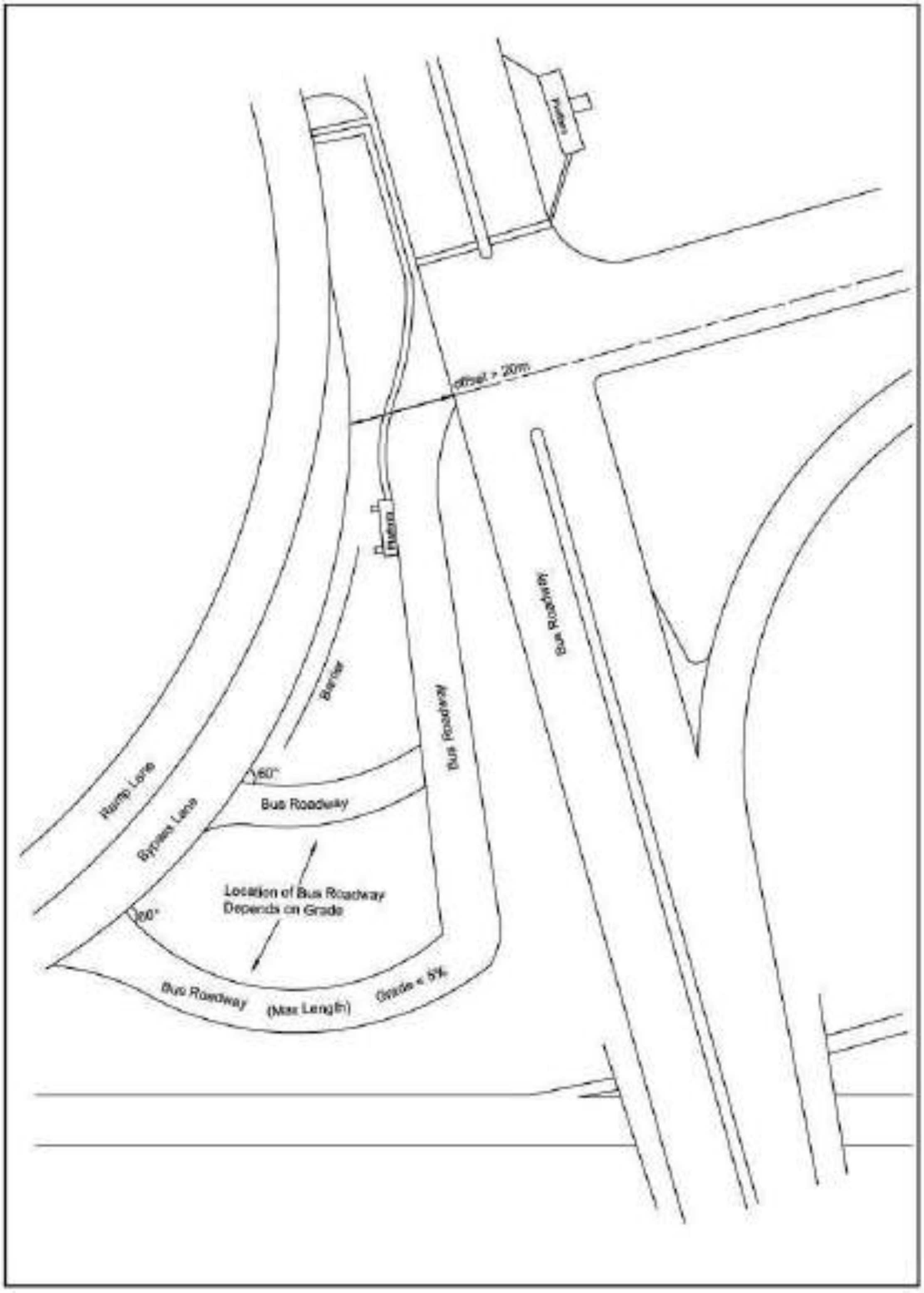


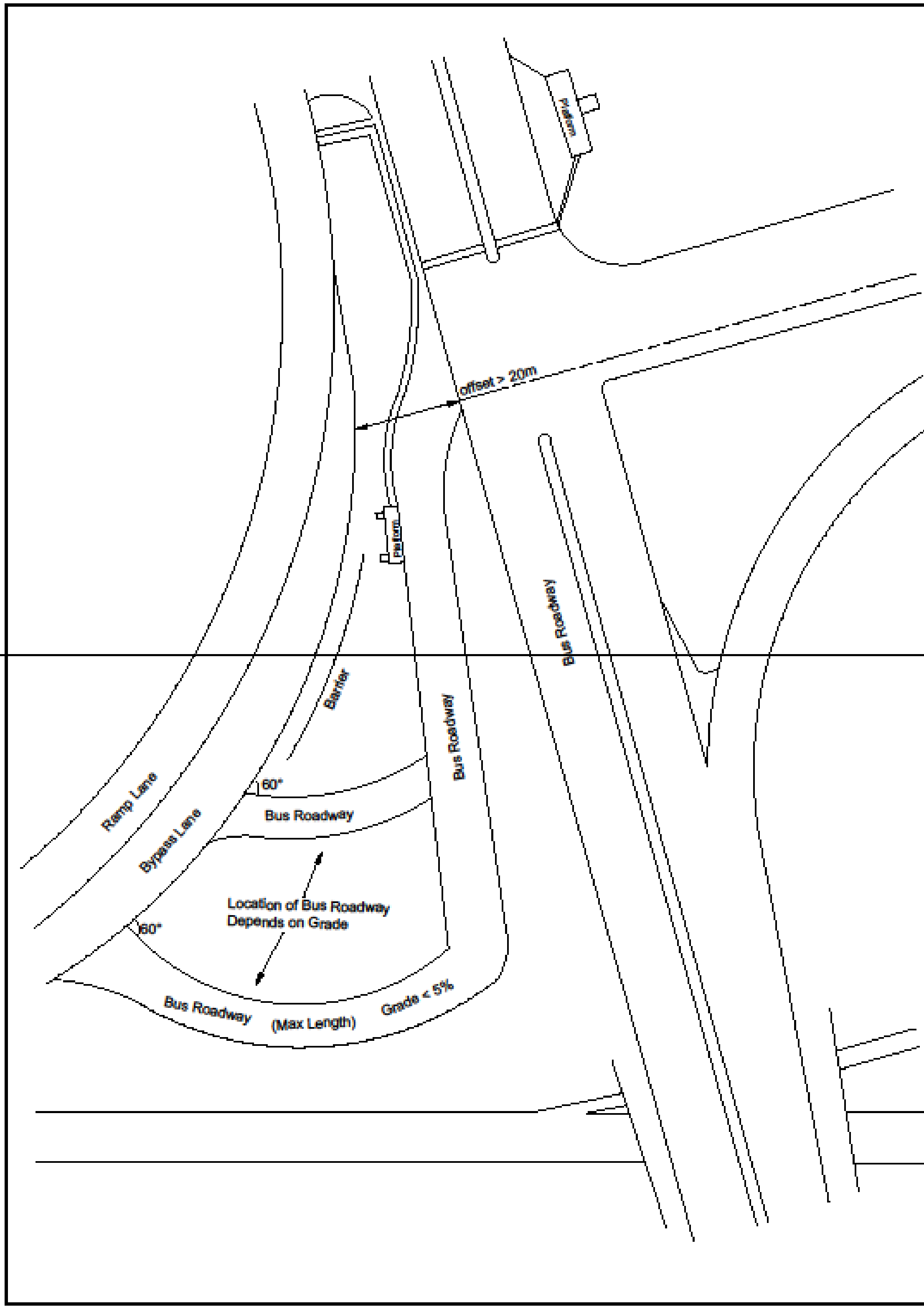


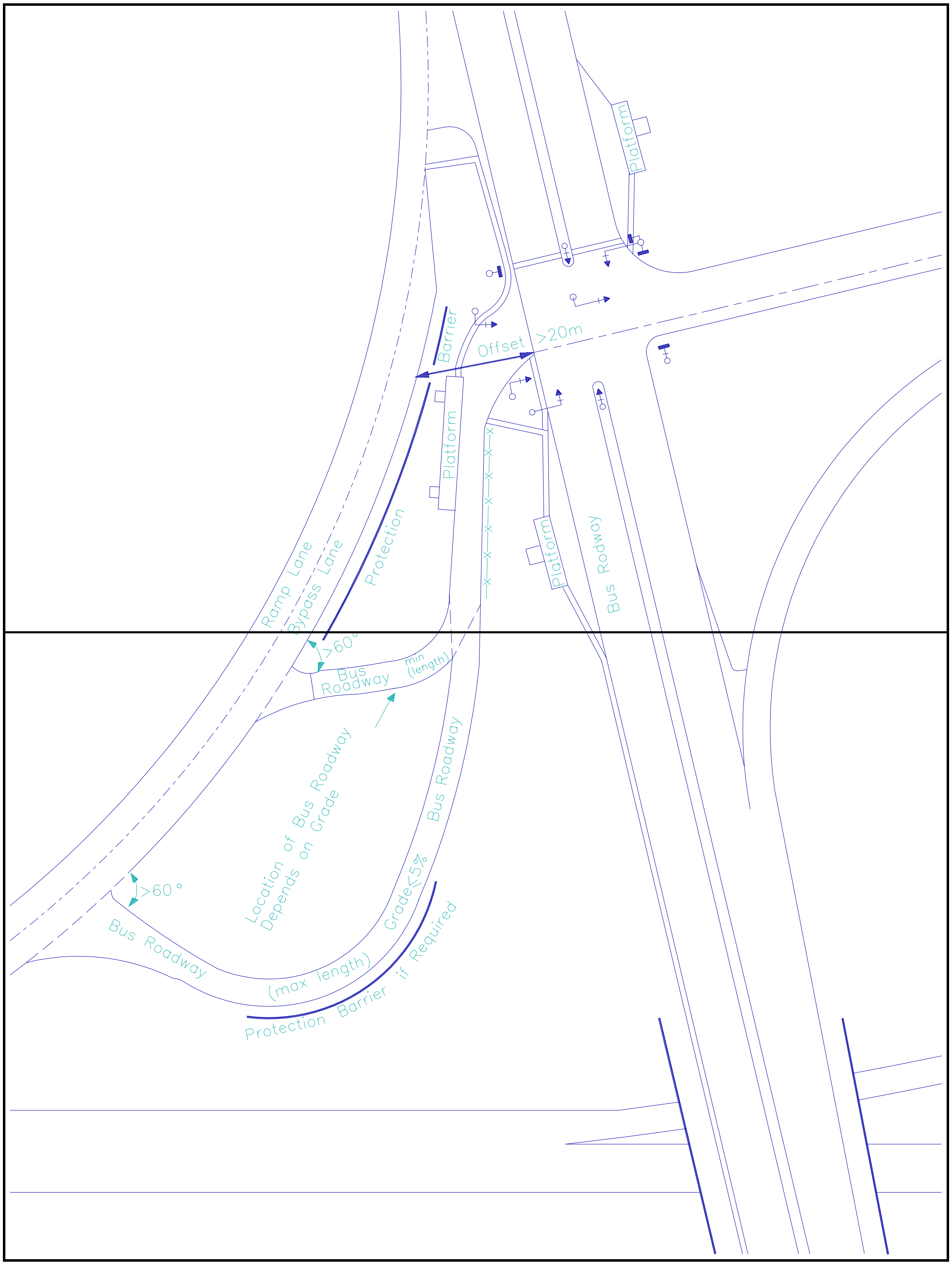
~~Figure 12.11.6 Freeway Interchange Bus Interface TYPE I~~

Exhibit 12CL

Freeway Interchange Bus Interface TYPE II


Platform
offset > 20m
Platform
Bus Roadway
Barrier
Bus Roadway
60°
Bus Roadway
Ramp Lane
Bypass Lane
Location of Bus Roadway
Depends on Grade
60°
Bus Roadway
(Max Length)
Grade < 5%

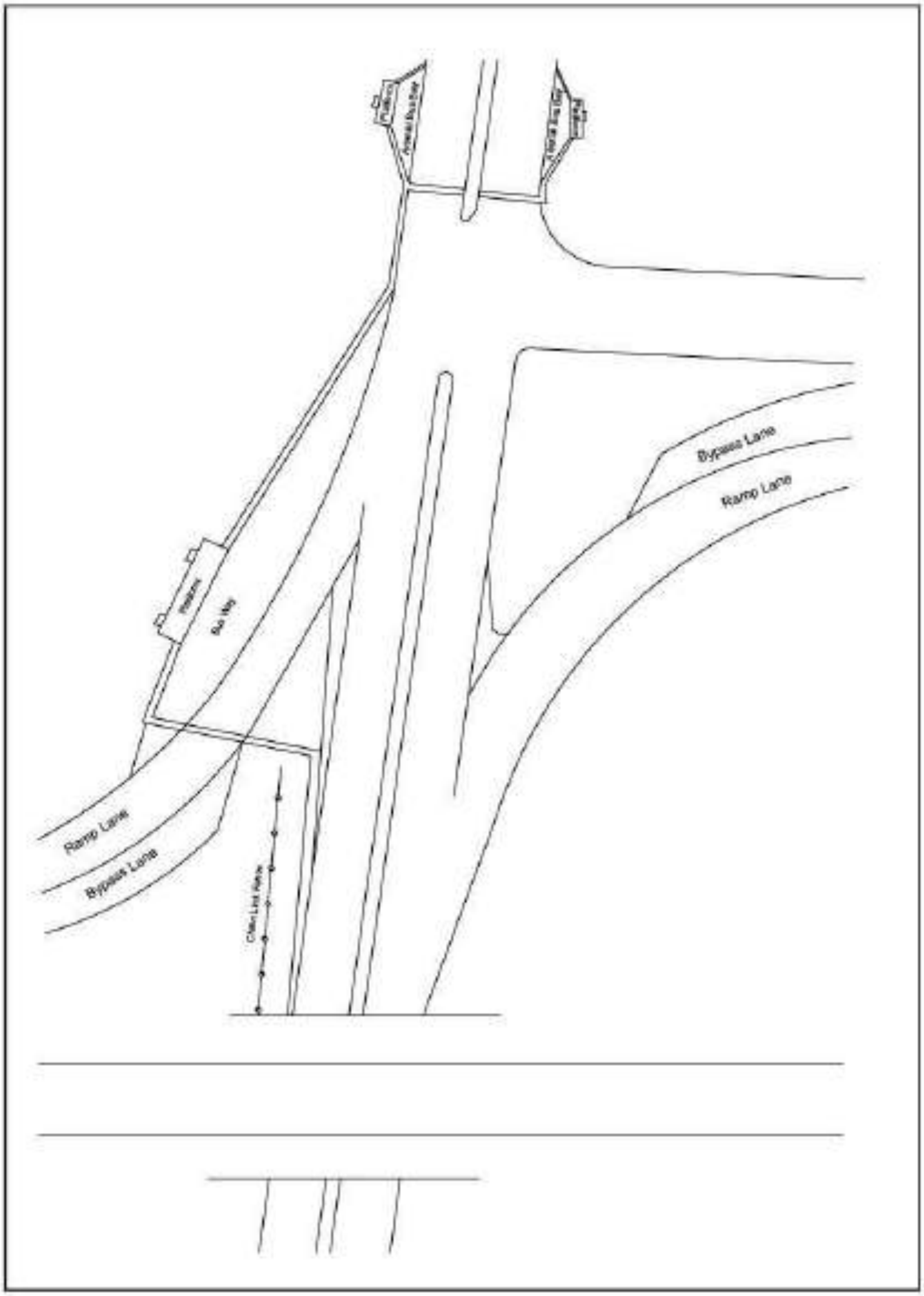

Platform
offset > 20m
Platform
Bus Roadway
Barrier
Bus Roadway
60°
Ramp Lane
Bus Roadway
Bypass Lane
Location of Bus Roadway
Depends on Grade
60°
Bus Roadway
(Max Length)
Grade < 5%

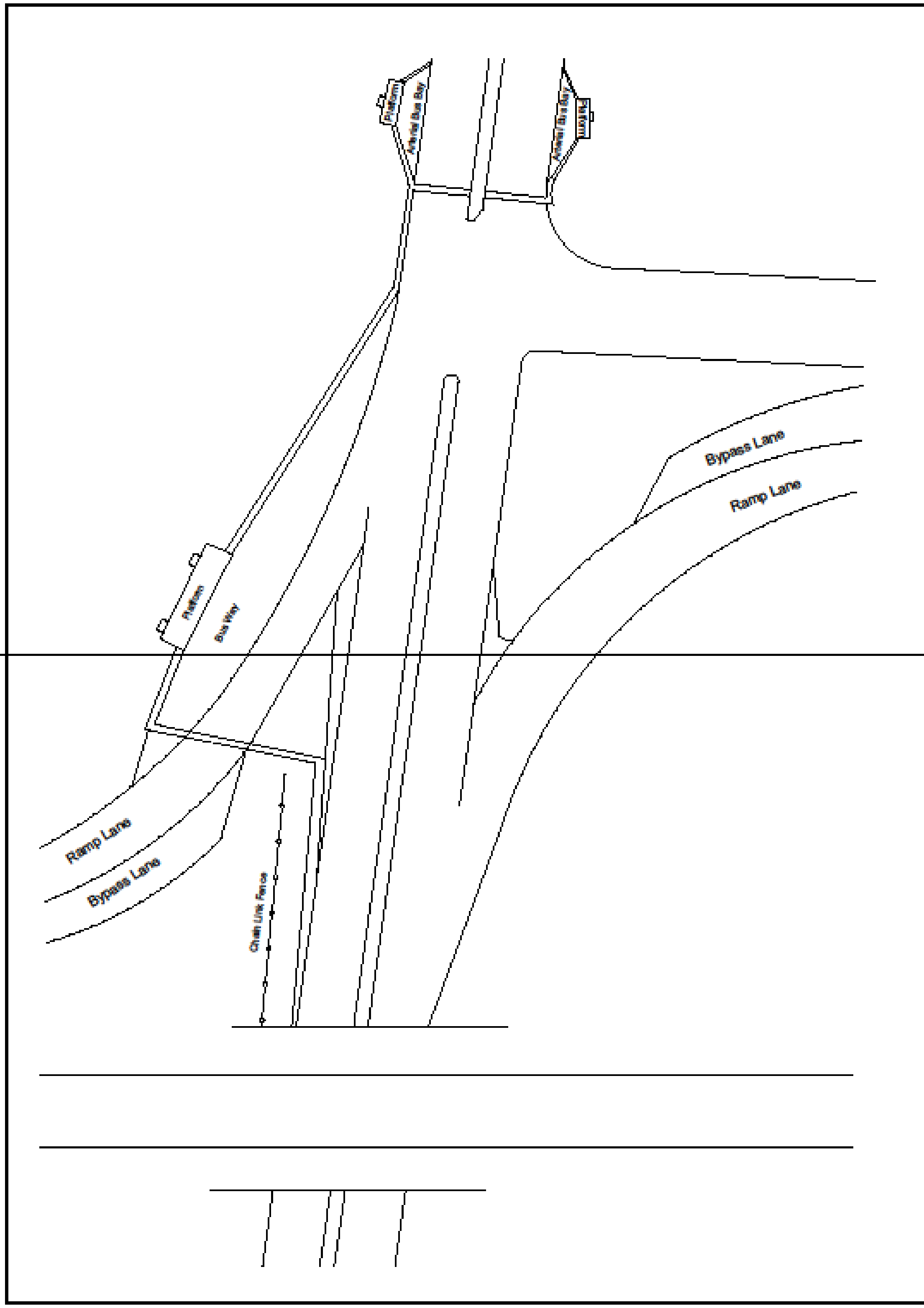


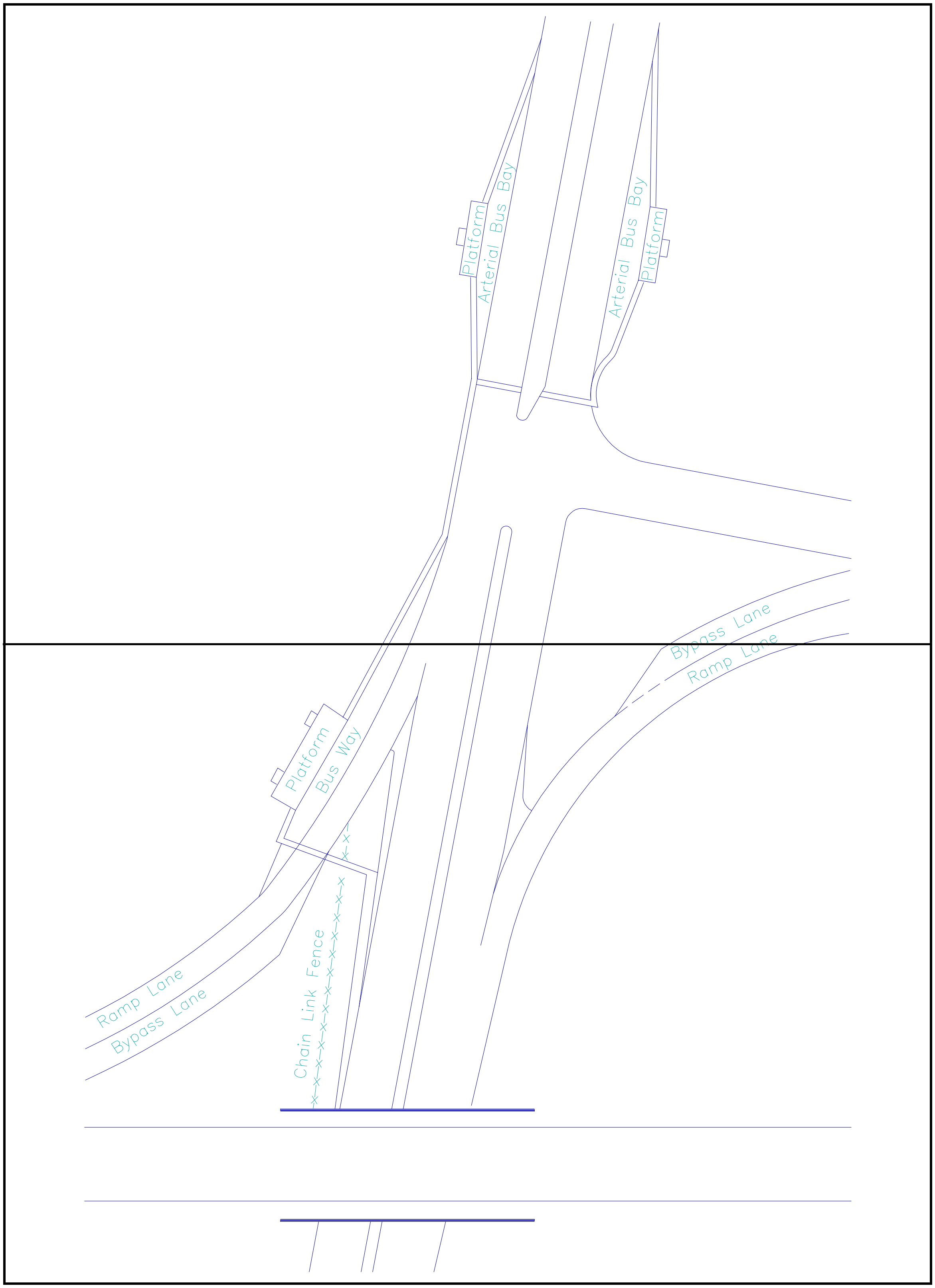
~~Figure 12.11.7 Freeway Interchange Bus Interface TYPE II~~

Exhibit 12CM

Freeway Interchange Bus Interface TYPE III



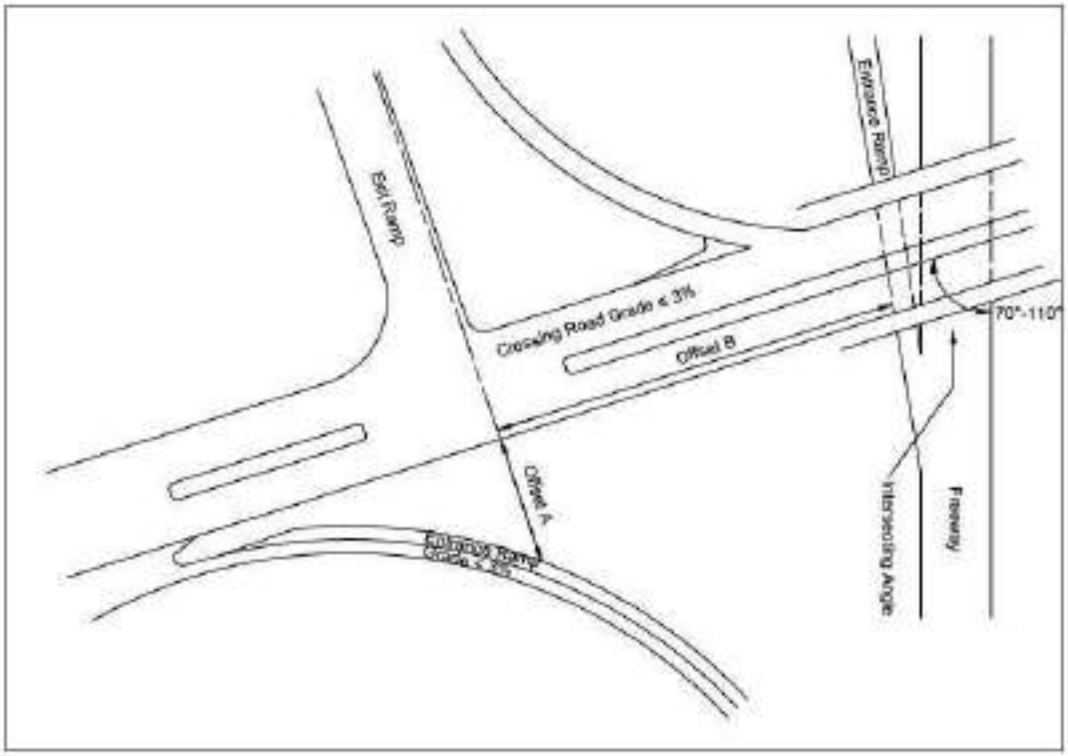

Platform
Arterial Bus Bay
Arterial Bus Bay
Platform
Bypass Lane
Ramp Lane
Platform
Bus Way
Ramp Lane
Bypass Lane
Chain Link Fence

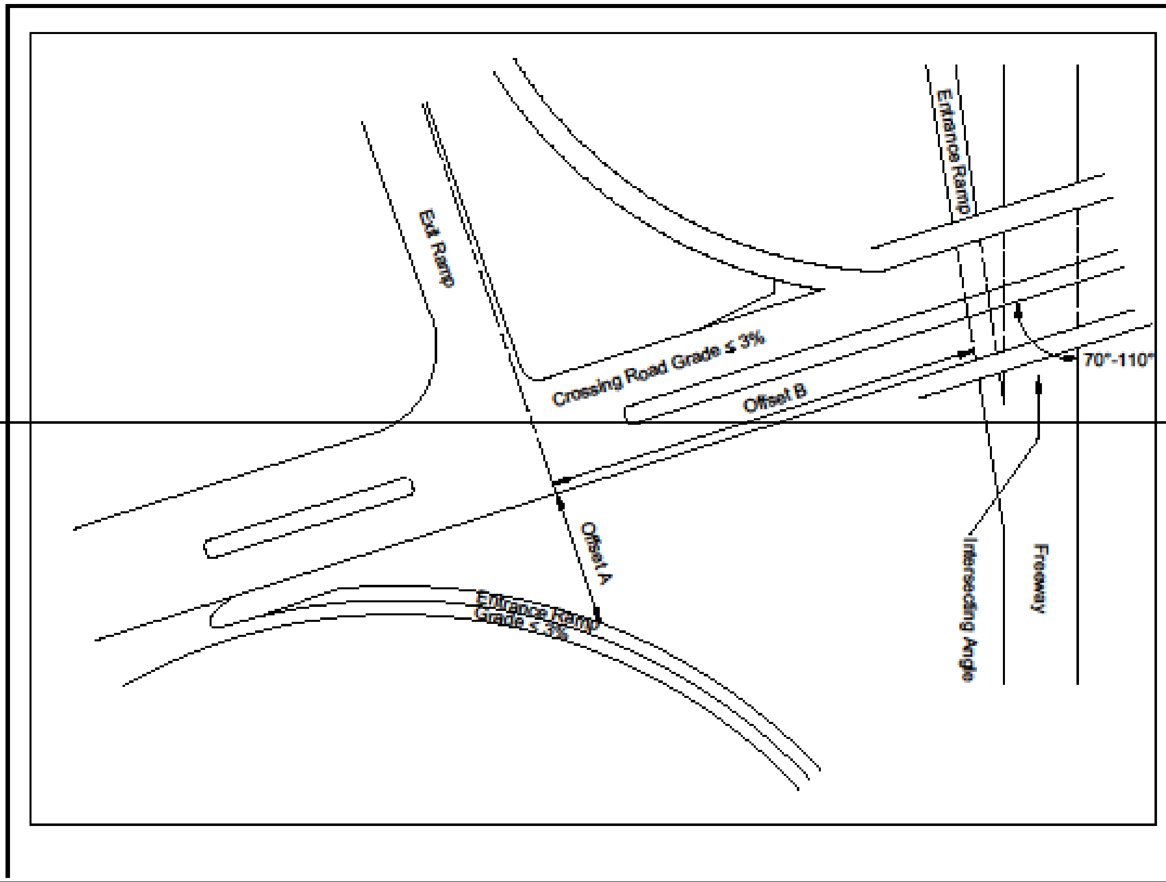


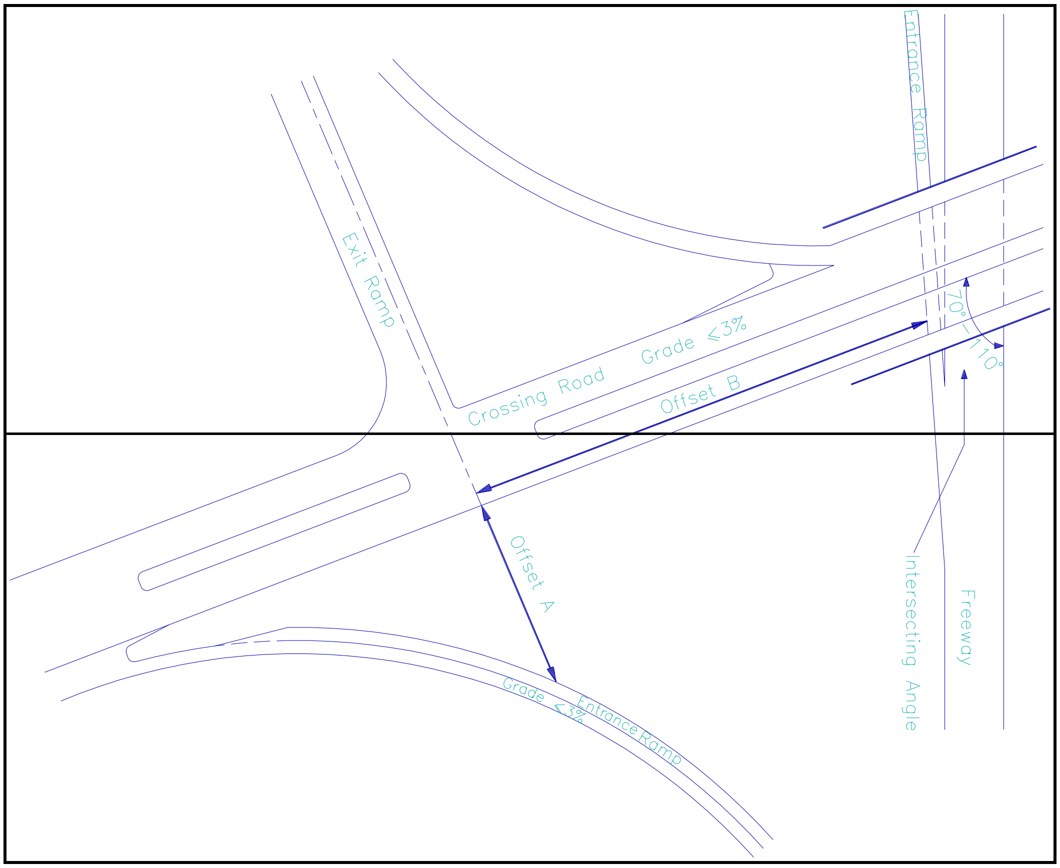
~~Figure 12.11.8 Freeway Interchange Bus Interface TYPE III~~

Exhibit 12CN

Interface of Freeway and Local Bus Services at "Parclo A" Interchanges (TYPE I & II)




Entrance Ramp
Exit Ramp
Crossing Road Grade ≤ 3%
Offset B
70°-110°
Offset A
Entrance Ramp
Grade ≤ 3%
Intersecting Angle
Freeway



~~**Figure 12.11.9 Interface of Freeway and Local Bus Services at "Parclo A" Interchanges (TYPE I & II)**~~

Guidelines

Step 1

- If intersecting angle is 70°-110° then proceed to step 2
- If angle is beyond this range, then proceed with layout of bus interface

Step 2

- If "OFFSET A" is >20 m then "OFFSET B" must be ³ 100 m to provide TYPE II interface
- If "OFFSET A" is 10-20 m and intersecting angle is ³ 90° then "OFFSET B" must be ³ 140 m to provide TYPE I interface with or without local bus exit
- If "OFFSET A" is 10-20 m and intersecting angle is < 90° then proceed with layout of bus interface
- If "OFFSET A" is < 10 m then proceed with layout of bus interface

Step 3

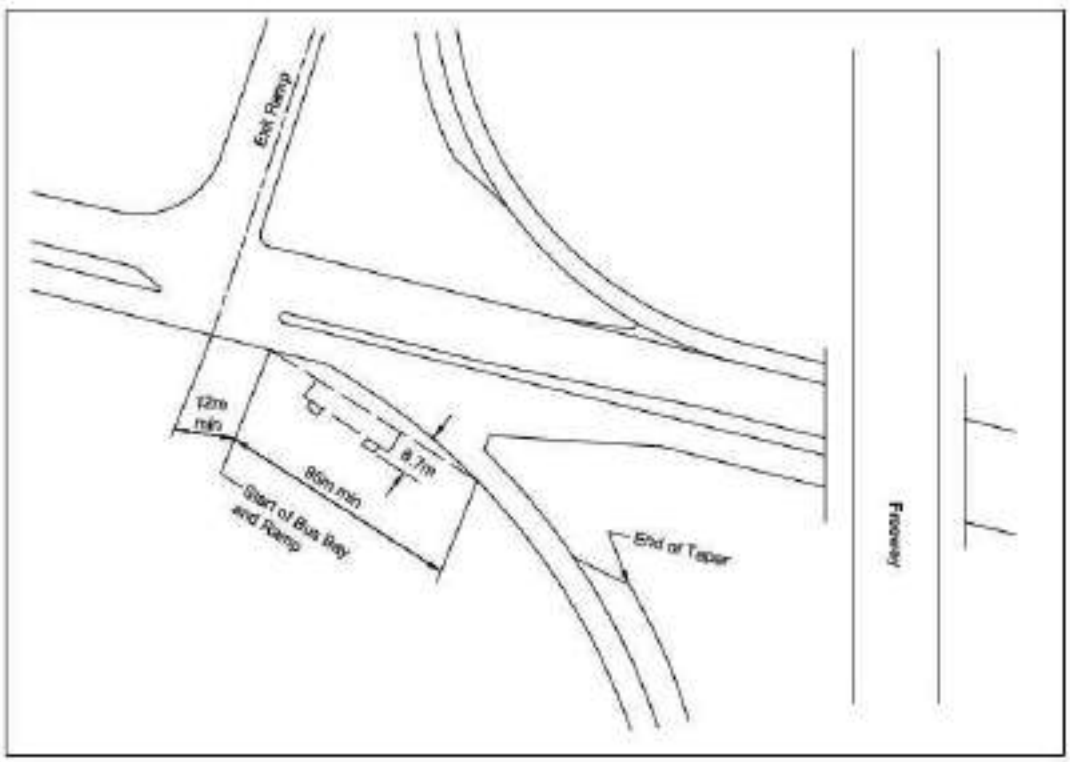
- Provide crossing road grade of 3% for TYPE I interface with or without local bus exit

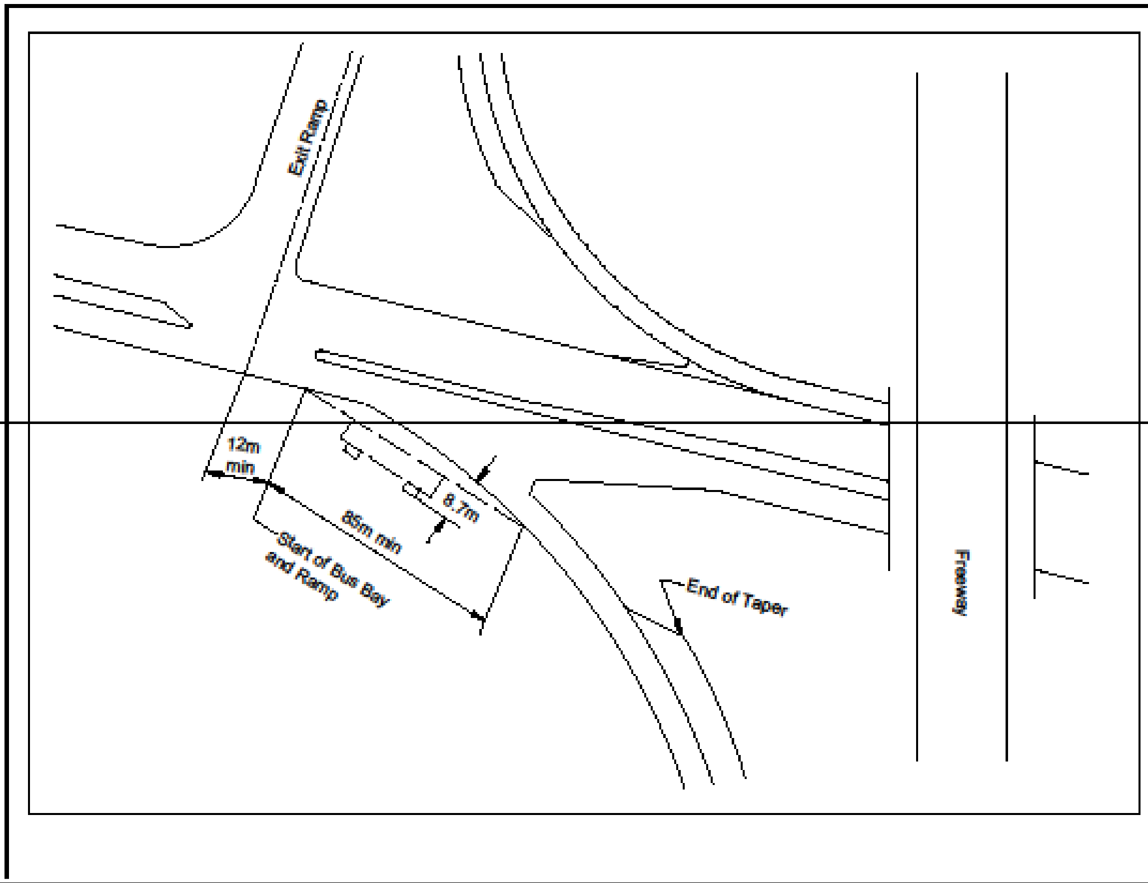
- Provide entrance ramp grade of 3% for TYPE I or TYPE II interface
- If grades are > 3% then proceed with layout of bus interface

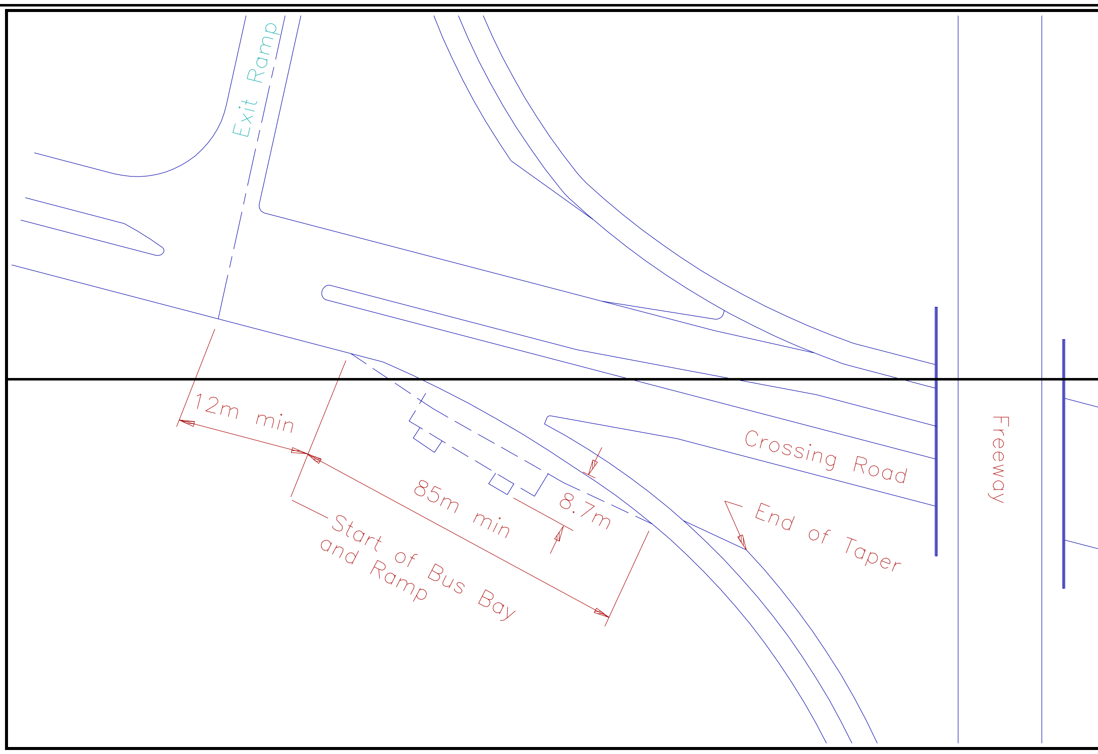
Note: These guidelines are intended for use in conceptual, functional and preliminary design of interchanges only. Design standards should be followed in pre-design and detail design.

Exhibit 12CO

Interface of Freeway and Local Bus Services at "Parclo A" Interchanges (TYPE III)







~~**Figure 12.11.10 Interface of Freeway and Local Bus Services at "Parclo A" Interchanges (TYPE III)**~~

Guidelines

Step 1

- If bypass ramp lanes are being considered for eventual construction, then proceed to STEP 2
- If not, then ensure that an envelope of land is available adjacent to the freeway ramp such that the bus bay can be constructed and will not interfere with arterial operations.
- Length of bus bay measured along the ramp should be 35 m and width from the outside edge of ramp to back edge of bus shelter, along the platforms should be 8.7 m.
- Ensure that buses turning left from the freeway exit ramp can manoeuvre into the bus bay at an appropriate approach angle. (A minimum distance of 12 m from bus turning lane to start of bus bay)

Step 2

- Locate the downstream end of the bus bay 85.0 m along the ramp from the start of the curve on the arterial~~.~~
- Ensure that the downstream end of the bus bay is adjacent to or upstream of end of taper/start of the bypass lane (the point at which 2 vehicles can travel side-by-side)
- Ensure that buses turning left from the freeway exit ramp can manoeuvre into the bus bay at an appropriate approach angle~~.~~ (A minimum distance of 12 m from bus turning lane to start of bus bay)
- For the length of the platform provide an offset from edge of ramp of 8.7 m.

Note: These guidelines are intended for use in conceptual, functional and preliminary design of interchanges only. Design standards should be followed in pre-design and detail design.

12.11.3 Bus Interface at Parclo “A” Interchanges

Five parameters are used to define the Type I and II bus interface space requirements:

- Offset from crossing road at exit ramp to direct entrance ramp with by-pass lane (if required)
- Offset from exit ramp along crossing road to edge of pavement at freeway or inner loop entrance ramp
- Intersection angle of the roadways
- Grade of the crossing road

- Grade of the direct entrance ramp~~.~~

Two parameters are used to define the Type III bus interface space requirements:

- Length along the direct entrance ramp, between the start of the bypass lane (the point at which 2 vehicles can travel side-by-side) and the upstream end of the bus bay.
- Offset from the edge of the entrance ramp which will accommodate the bus bay and the platform area and a bus shelter.

These guidelines should be appropriate for most applications, however, if conditions are restricting then a layout of the interface should be undertaken using the Design Standards.

12.11.3. 1 Selection of Interface Type

~~1.~~ Interface Type I

1.

In cases where an offset between the Freeway exit terminal and entrance ramp of 10 - 20 m is provided, develop crossing road profile and entrance ramp profile to permit possible implementation of Type I Freeway Interchange Bus Interface (**Exhibit 12CK~~Figure 12.11.6~~**) with:

- A bus platform length of 35 m~~;~~
- A bus roadway at a 0.5% longitudinal grade between the crossing road and the downstream end of the platform~~;~~
- A bus roadway at a grade of no more than 5% with appropriate vertical transition curves between the platform and the freeway entrance ramp~~;~~
- I~~i~~n cases where the climbing grade of the crossing road permits it, a bus roadway at a grade of not more than 5% with appropriate vertical transition curves between the platform and the re-entry point at the crossing road~~; or,~~
- In cases where the climbing grade of the crossing road does not permit local bus re-entry onto the crossing road, a separate local bus bay to be located along the crossing road before the crossing road structure~~.~~

2. Interface Type II

In cases where an offset between the Freeway exit terminal and entrance ramp of at least 20 metres is available, develop crossing road profile and entrance ramp profile to permit possible implementation of Type II Freeway Interchange Bus Interface (**Exhibit 12CL**~~**Figure 12.11.7**~~) with:

- (i) Aa bus platform length of 35 m~~etres;~~
- (ii) Aa bus roadway at a 0.5% longitudinal grade between the crossing road and the downstream end of the platform~~; an d~~
- ~~(i)~~(iii) Aa bus roadway at a grade of no more than 5% with appropriate vertical transition curves between the platform and the freeway entrance ramp~~.~~

3. ~~3.~~

In cases where an offset of less than 10 m is provided between the Freeway exit terminal and entrance ramp, develop a Type I Freeway Interchange Bus Interface as per #2 above at a point downstream of the Freeway exit terminal where necessary offset is available.

4.

~~4.~~ In cases where the crossing road exit terminal is downstream of the Freeway exit terminal. These guidelines suggest that in circumstances of new design, an offset of at least 20 m is sufficient to provide a Type II Bus Interface and possibly a Type I Bus Interface.- If property limitations or the skew of the crossing road to the freeway is such that an offset of 10 - 20 m results, then a Type I Bus Interface is appropriate with or without a separate local bus bay depending on local conditions.- If the offset is less than 10 m~~etres~~, then a Type I Bus Interface is still appropriate, but it must be located downstream of its normal position where sufficient offset is available.- If the Freeway entrance ramp is accessed downstream of the Freeway exit ramp, then a new design is required which is not yet developed.

5~~3~~. Interface Type III

This additional geometric design standard provides guidance in providing for an interface at Parclo "A" Interchanges which are configured such that the freeway direct entrance ramp is located downstream along the crossing road from the exit ramp terminal. -This Type III bus interface which is most suitable to this interchange configuration is indicated in **Exhibit 12CM**~~**Figure 12.11.8**~~.

12.11.3.2 Operational Considerations

(i) Interface Type I and II

Bus access to the bus interface will be from the exit ramp left-turn lane in situations where the exit ramp terminal at the crossing road is 2 lanes.

Bus access to the bus interface will be from the ~~center~~centre freeway exit ramp either/or turn lane in situations where the freeway exit ramp terminal at the crossing road is 3 lanes.- Location and alignment of the bus interface entrance shall be designed such that conflicts between turning traffic in adjacent lanes is avoided.

Buses will access the bus roadway and stop at one of two possible bus platforms at the interface.

Buses can proceed through the interface platform area at speeds not exceeding 35 km/h which has been established as reasonable from the point of view of manoeuvrability, safety and costs.

During unmetered times of the day, buses will likely enter directly into the main traffic flow from the bus roadway.

Passengers will access the bus interface by either transferring from local transit or walking in from the crossing road.

Access will be directly to the platform since fares will likely be collected on-board the buses. Platform access can be at either end or along its length.

(ii) Interface Type III

As with all freeway bus operations, bus access to the Type III interface will be from the exit ramp left turn lane in situations where the exit ramp terminal at the crossing road is only 2 lanes.

Bus access to the Type III bus interface will be from the centre freeway exit ramp either/or turn lane in situations where the freeway exit ramp terminal at the crossing road is 3 lanes. -Location and alignment of the Type III bus interface entrance shall be designed such that conflicts between turning traffic in adjacent lanes is avoided.

Buses will access the Type III interface at the freeway entrance ramp terminal and stop at one of two possible bus platforms.

Buses will exit from the platforms directly onto the ramp when there is a suitable break in traffic flow.- If there is a bypass lane and a metered lane on the ramp and if metering is in operation, then the bus may move left into the bypass lane without undue weaving difficulties. -At such time that metering is not in operation then the bus may stay in the main flow of traffic.

Passengers will access the Type III bus interface by walking from local bus bays on either side of the arterial or by crossing the freeway entrance ramp from the other side of the interchange.

Passenger access to buses will be uncomplicated since fares will likely be collected on-board the buses and not at turnstiles at the ends of the platforms. -This allows platforms to be accessed from the ends or along its length. -If the access is along its length, then additional offset from the ramp will be required.

12.11.3.3 Staging Considerations

Integration of the bus system with the ultimate rail system has been considered and it is anticipated that bus interfaces will be operational during the integration process.

Transitway sections between interchanges will ultimately be linked together with grade-separated structures, however at an interim measure, at-grade bus crossings could possibly be developed. -This condition may have traffic operational improvements or geometric design provisions then it may be possible to utilize the initial bus interfaces to facilitate transfers between local buses and freeway buses. -The Type I Bus Interface however does not permit left turns into the bus roadway from the crossing road due to its inherent design characteristics.

Full development of transit service staging should be undertaken during preliminary design activities for the transitway.

If at-grade bus crossing impacts are minimized through traffic operational improvements or geometric design provisions, then it may be possible to utilize the initial Type III bus interfaces to facilitate transfers between local buses and freeway buses during the interim time frame.

12.11.3.-4 Design Standards

The design should consider desirable alignment elements which improve passenger ride, such as reducing sags, crests and directional changes while moderating costs.

Design of Bus Interfaces should consider:

- S~~s~~afety
- C~~c~~apital costs
- A~~a~~lignment
- I~~i~~ntended operation
- I~~i~~mpact on crossing road and bus roadway access/egress locations

Design speeds shall be 35 km/h on bus roadways and platform areas.

12.11.3.~~4~~.1 Horizontal Alignment

Sufficient sight distance shall be provided for buses on the bus roadway such that drivers can maintain safe and efficient operation of the vehicles. Minimum stopping sight distance must be provided at egress to the freeway entrance ramp.

Passing sight distance does not apply since no passing will occur on the bus roadway except the passing of stalled or immobile vehicles.

The bus roadway shall be on tangent through the platform area.

Minimum edge of pavement radii for the B-12 design vehicle are as follows:

Stop Condition (0 - 15 km/h)	Radii: 18 m
Yield Condition (15 - 25 km/h)	Radii: 20 m

Note that on a four-lane roadway with a 15 m radius, buses use both lanes when making a right turn.

12.11.3.~~4~~.2 Vertical Alignment

The maximum gradient on the bus roadway shall not exceed 5%, as depicted on **~~Figures 12.11.~~Exhibit 12CP~~11~~**.

The minimum gradient on the bus roadway should be no less than 0.5% at platforms to permit positive drainage.

The design parameter for crest curves and sag curves on the bus roadway shall remain above a minimum K = 4 m for crest and K = 8 m for sag curves (at 40 km/h).

12.11.3.~~-~~4.3 Turning Vehicle Paths

The **Design Vehicle** dimensions shall be used to ensure that highway buses can manoeuvre easily on bus interface sites. -The highway bus type B-12 shall be the design vehicle for all bus interface layouts.- This design vehicle will accommodate standard Buses.

A clearance of at least 1.0 m should be provided between the line given by the Design Vehicle Turning Radius and any fixed object that a bus could collide with.

There are two paths for the design vehicle, as follows:

Stop Condition

The vehicle commences a turn from a stationary position (e.g. from bus platform on bus roadway). Stop condition reflects the treatment for stop sign control where the access road joins a two-lane roadway, using the 15 m turning radius design vehicle template.

Yield Condition

The vehicle commences a turn at speeds between 15 and 25 km/h (e.g. downstream of platform along bus roadway). Yield condition reflects the treatment for signal control where an access road joins a two-lane roadway, using the 20 m turning design vehicle template.

12.11.3.4.4 Safety and Security Measures

Chain link security fencing shall be provided as required to encourage safety and pedestrian control in the bus interface area.

Fencing may be replaced by longitudinal traffic barrier with aluminium pedestrian barrier affixed to the top or fencing affixed to the top of a retaining wall if so required.

Longitudinal traffic barrier shall be installed along Freeway traffic entrance ramps where safety is at risk due to vehicles accidentally veering towards pedestrian areas of the interface.

Longitudinal barrier shall be installed if the unprotected clearance between the bus roadway and the freeway edge of pavement is within 10 m.

Such barrier shall be located in accordance with the latest edition of ministry's "**Roadside Design Manual**".

Provisions are to be made for access by emergency vehicles, including fire trucks and ambulances. -Designated fire routes, no parking zones, etc., shall meet municipal approval, although emergency vehicles will generally use bus roadways.

12.11.3.5 Interface Location

Interfaces at interchanges shall be located as closely as practicable to crossing roads of suitable geometrics and ridership potential.

Pedestrian walk distances shall be minimized between local and freeway buses.

12.11.3.6 Platform Facilities

Standardized bus interface designs shall be provided if practical.

Geometric design provisions at bus interfaces should allow for platforms to be 35 m long, 4 m wide and the bus platform level should be 150 mm above the bus pavement level.

Satellite shelter pads should be provided for along the platform such that a 1.2 m by 3.65 m shelter (approximate dimensions) could be constructed.

Lighting of the bus roadway, and the platforms, and of sidewalks and shelters should be integrated with that of the ramp and crossing road.- Under pavement crossings should be provided accordingly.

12.11.3.7 Local Bus Facilities

Where freeway bus interfaces are located adjacent to crossing roads, the municipality may request that bus bays for local service be provided, particularly if the interface cannot accommodate local bus facilities. -Bus bays will assist the through traffic movement and reduce the accident-prone weaving movement on four and six-lane roads.

The location and dimensions of the bus bay must be reviewed with the transit authority to ensure that the location suits their operations. -It will also require a careful site review to ensure that conflicts with driveways or other topographic features are minimized, and that the location is approved by the municipality. -Typical configurations are provided on **Exhibit**

12CR~~Figure 12.11.13~~.

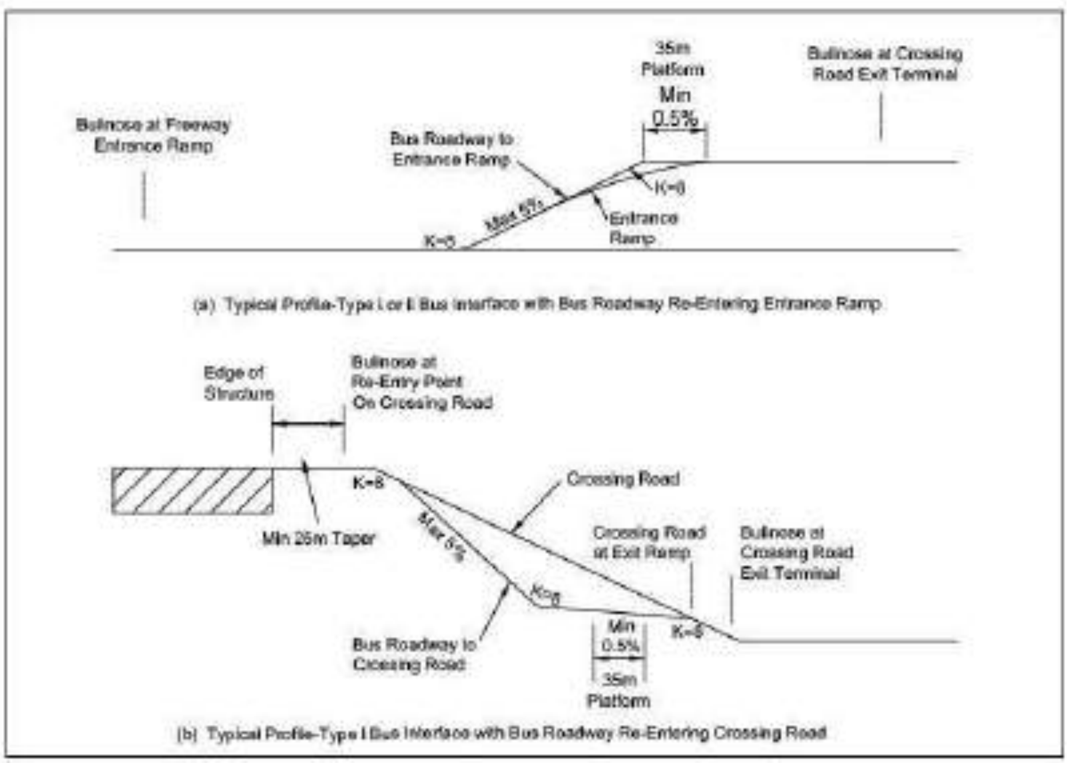
Care must be taken in the bus bay design allowing appropriate entrance and exit lengths to discourage serious disruption of traffic movement in the adjacent lanes. -Both Standard and some models of Articulated Buses (B-12) should be accommodated in bus bay design.

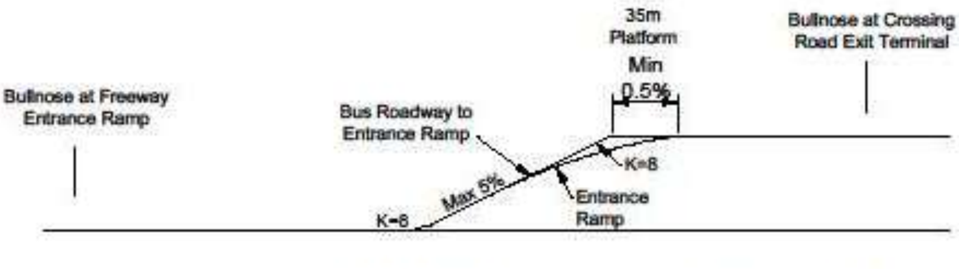
Local buses travelling in one direction on the crossing road may be provided with bus stopping privileges at freeway bus platforms for Type I interfaces where the offset between the crossing road and the freeway entrance ramp permits it and where the grade differential is small. -This arrangement provides optimum passenger transfer potential between buses. -Under favourable circumstances local buses then re-enter the crossing road upon leaving the interface.

Buses which may wish to turn left from the crossing road into the bus interface will be able to do so only at Type II interfaces. -Type I interfaces do not provide sufficient area in which to turn a bus from that position.

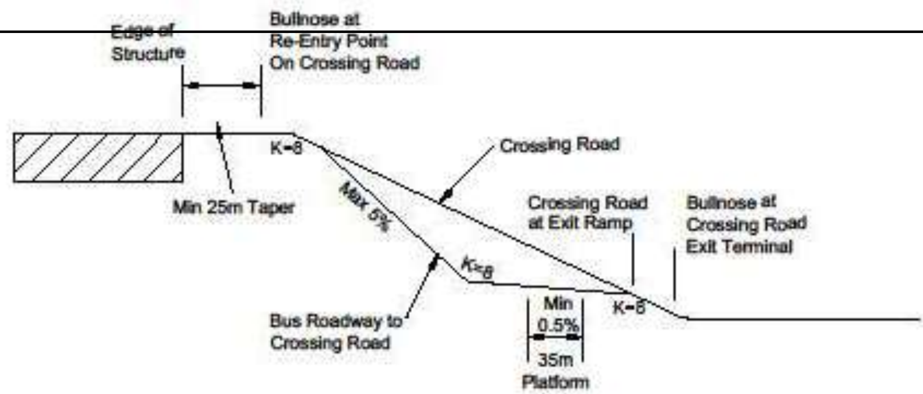
Exhibit 12CP

Typical Profile of Interchange with Bus Interface TYPES I, II &III

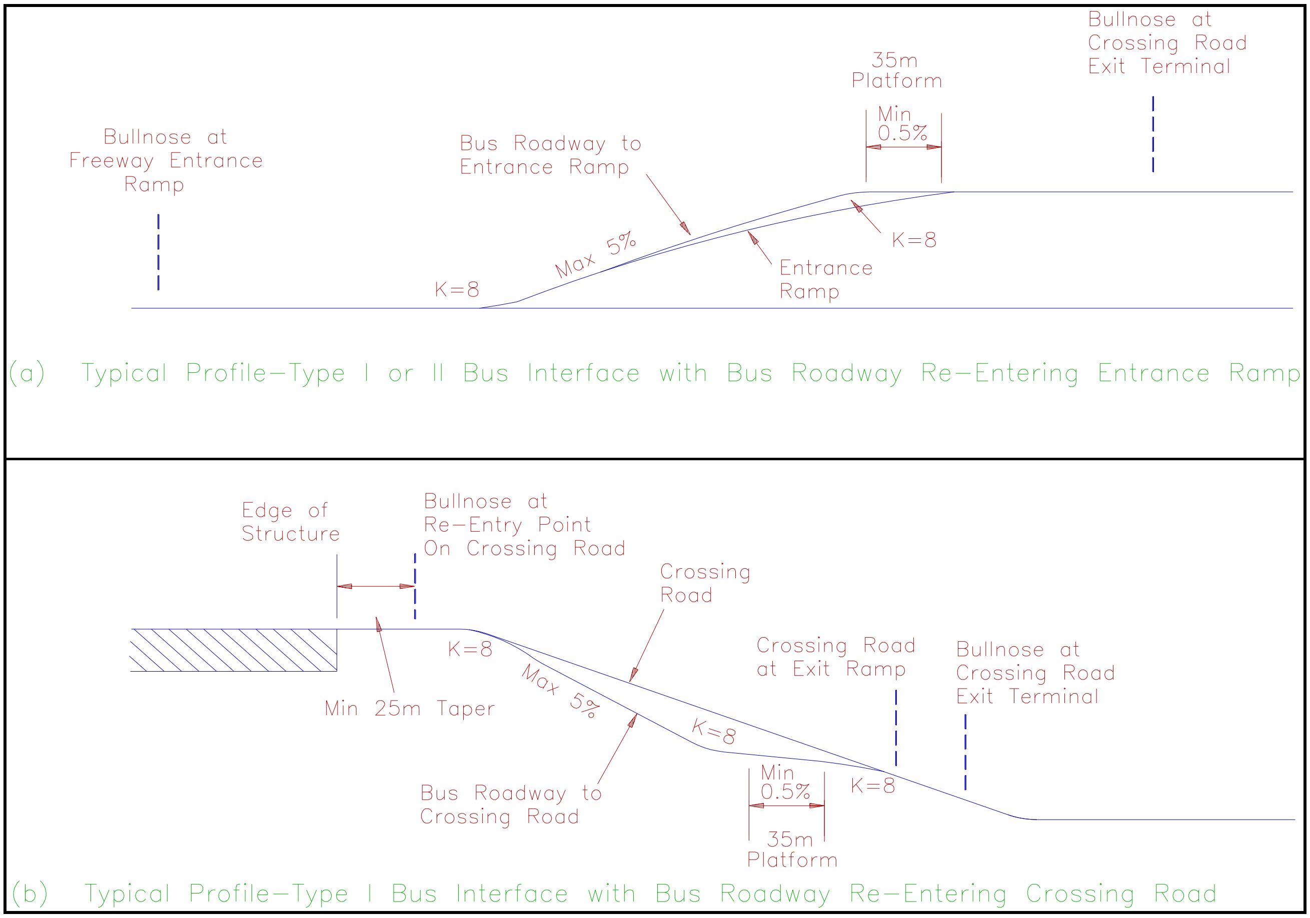




(a) Typical Profile-Type I or II Bus Interface with Bus Roadway Re-Entering Entrance Ramp



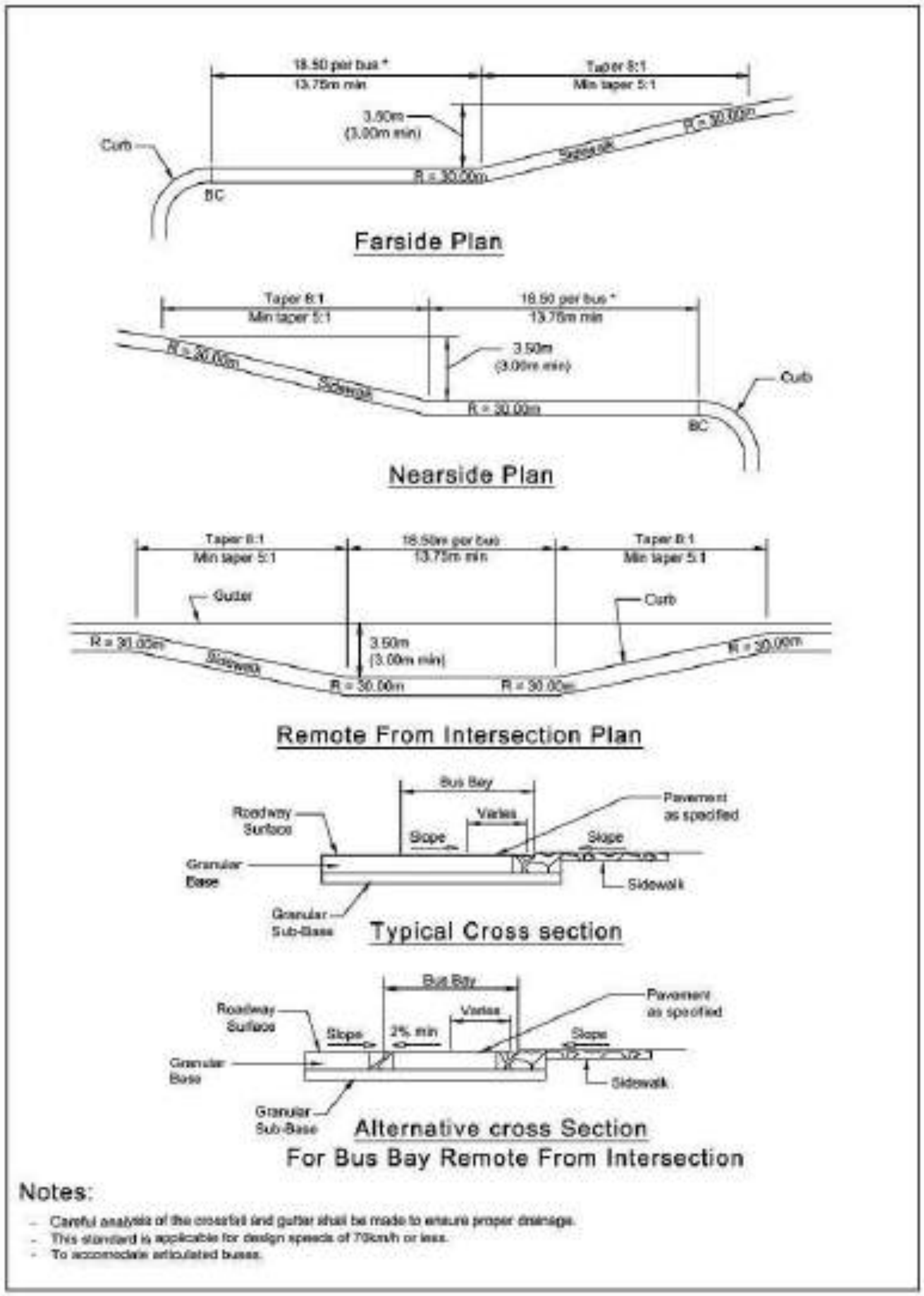
(b) Typical Profile-Type I Bus Interface with Bus Roadway Re-Entering Crossing Road

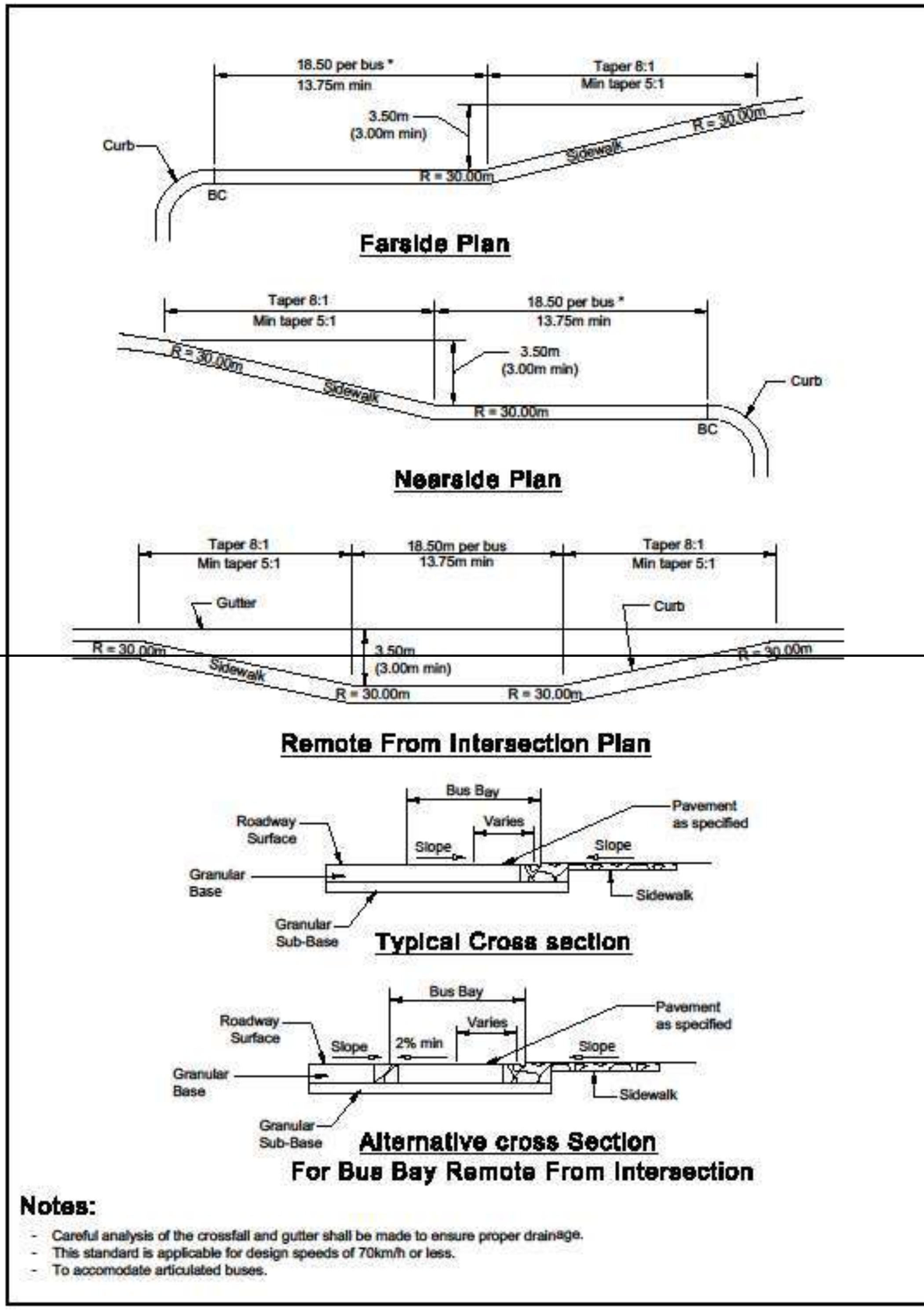


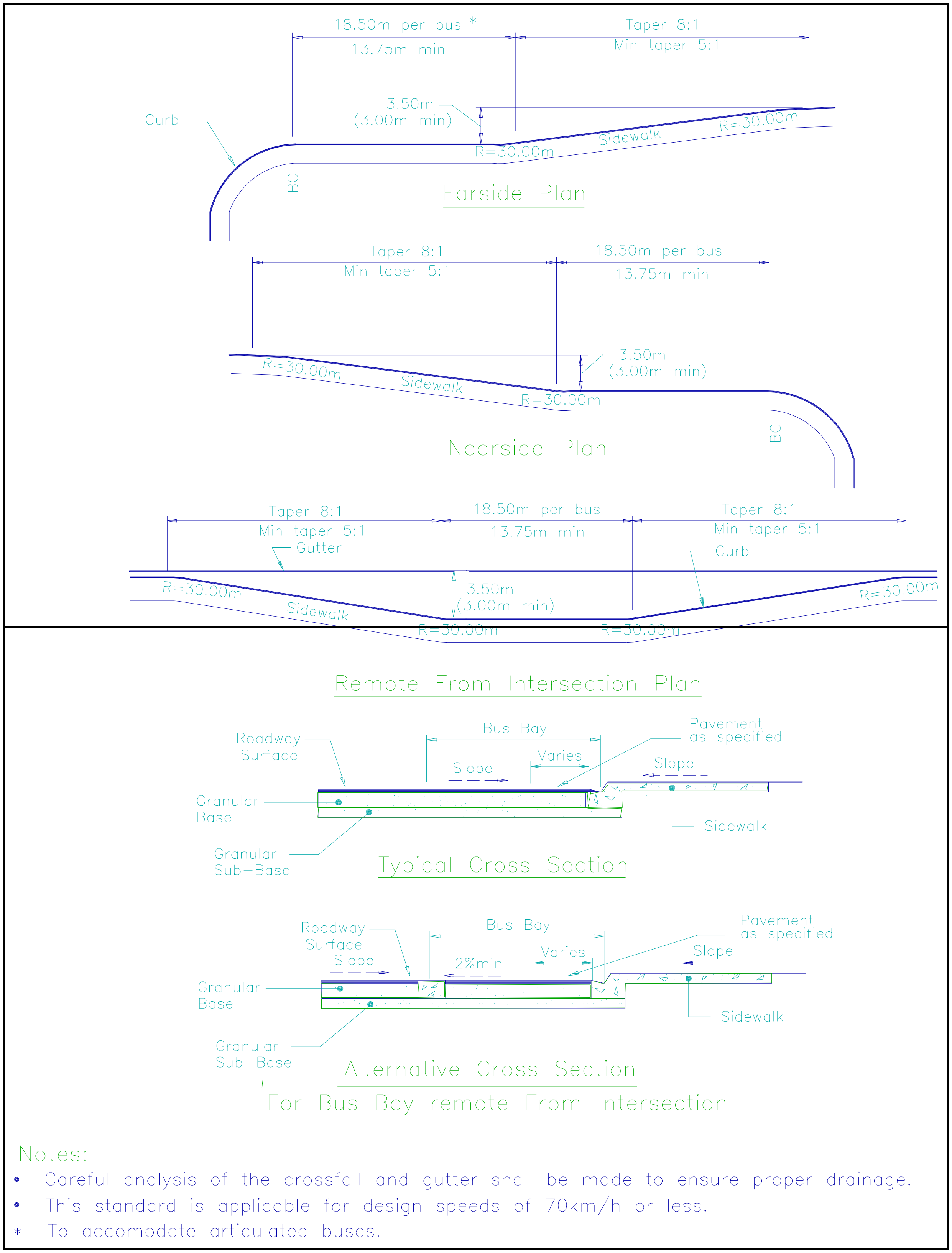
~~Figure 12.11.11 Typical Profile of Interchange with Bus Interface TYPES I, II &III~~

Exhibit 12CQ

Arterial Bus Bays

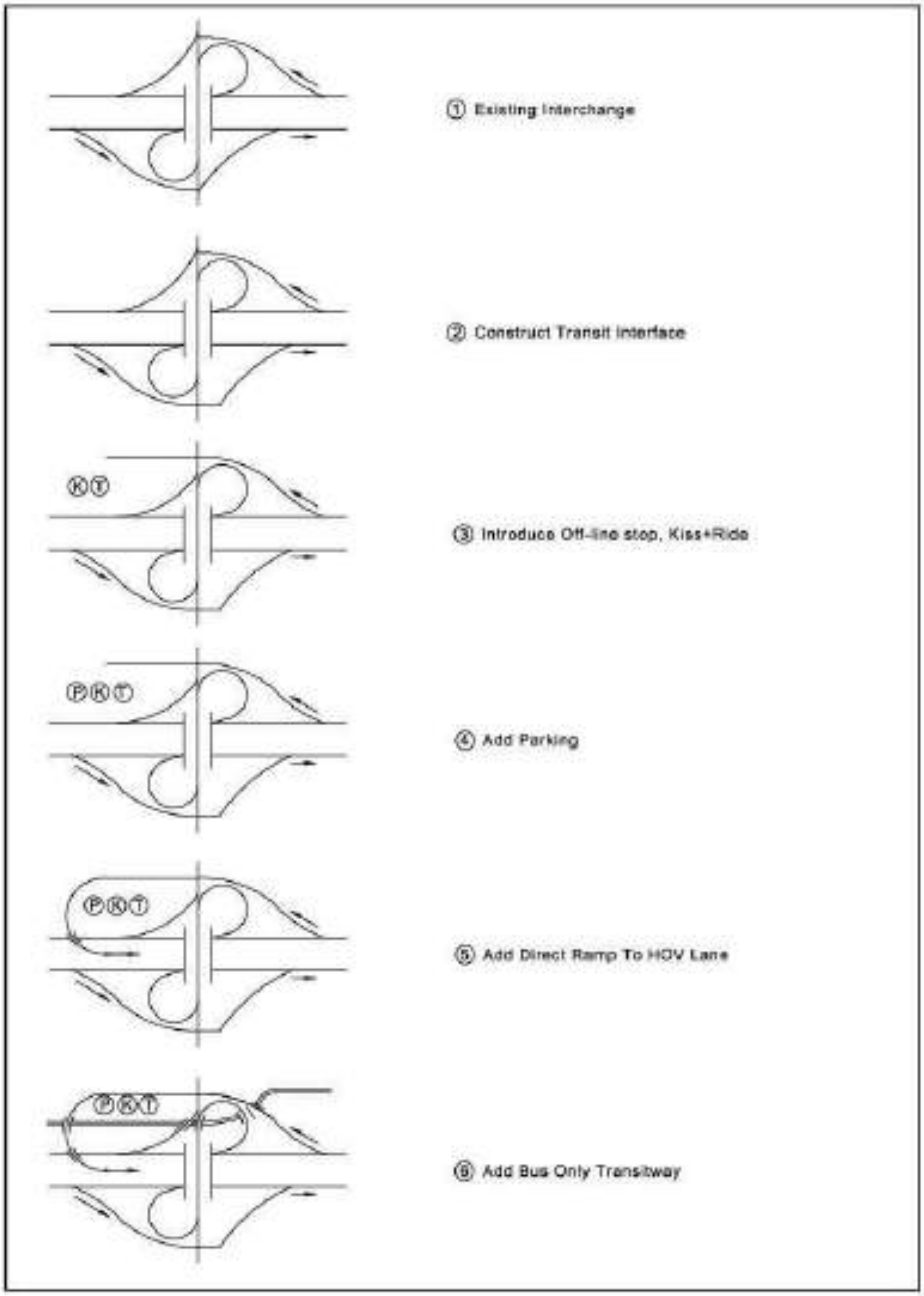


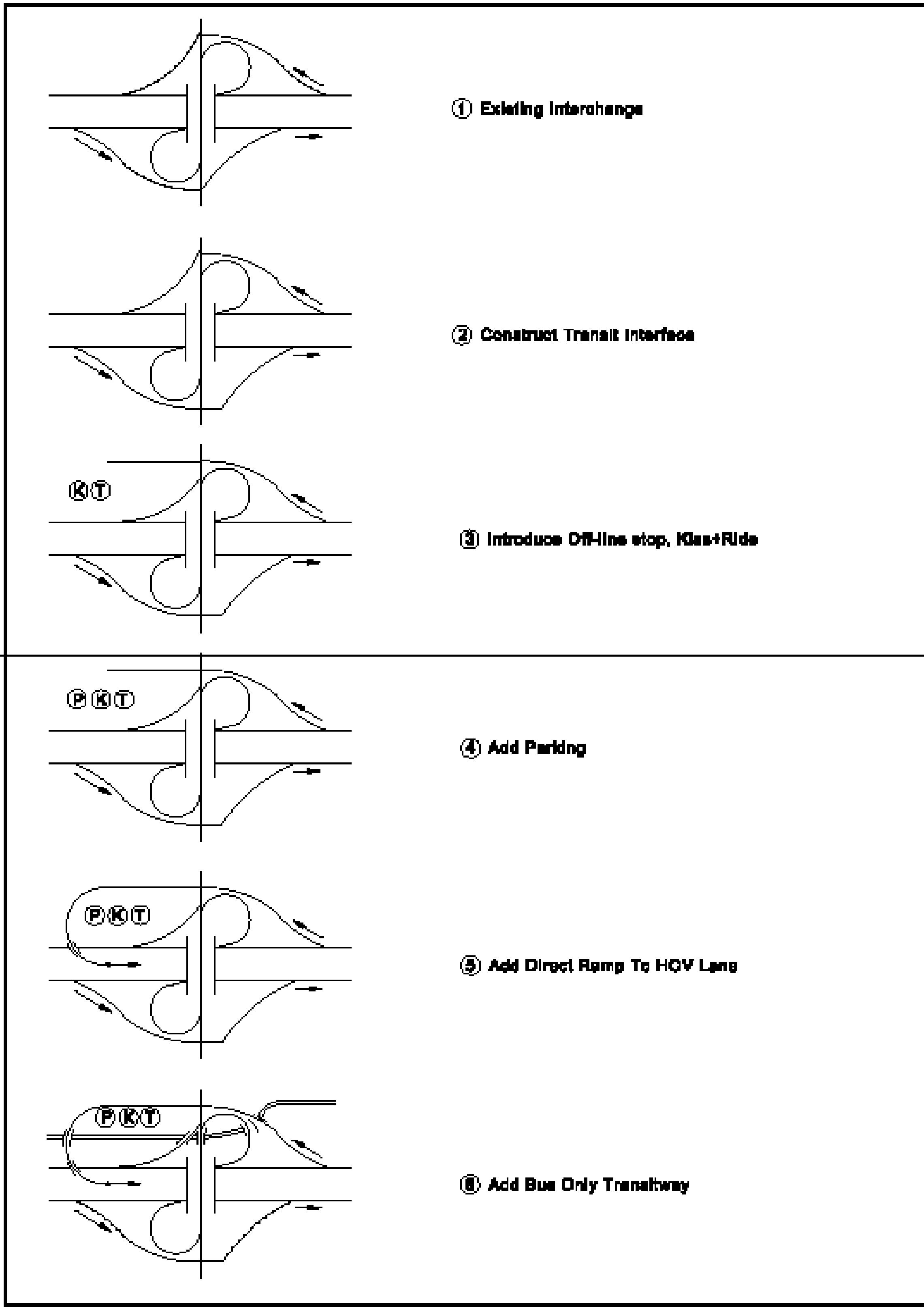

18.50 per bus *
13.75m min
Taper 8:1
Min taper 5:1
3.50m
(3.00m min)
Curb
BC
R = 30.00m
Sidewalk
Farside Plan
Taper 8:1
Min taper 5:1
18.50 per bus *
13.75m min
3.50m
(3.00m min)
Curb
R = 30.00m
Sidewalk
BC
Nearside Plan
Taper 8:1
Min taper 5:1
18.50m per bus
13.75m min
Gutter
Curb
R = 30.00m
3.50m
(3.00m min)
Sidewalk
Remote From Intersection Plan
Bus Bay
Varies
Roadway Surface
Slope
Pavement as specified
Granular Base
Granular Sub-Base
Sidewalk
Typical Cross section
Bus Bay
Varies
Roadway Surface
Slope
2% min
Pavement as specified
Granular Base
Granular Sub-Base
Sidewalk
Alternative cross Section
For Bus Bay Remote From Intersection
Notes:
- Careful analysis of the crossfall and gutter shall be made to ensure proper drainage.
- This standard is applicable for design speeds of 70km/h or less.
- To accomodate articulated buses.

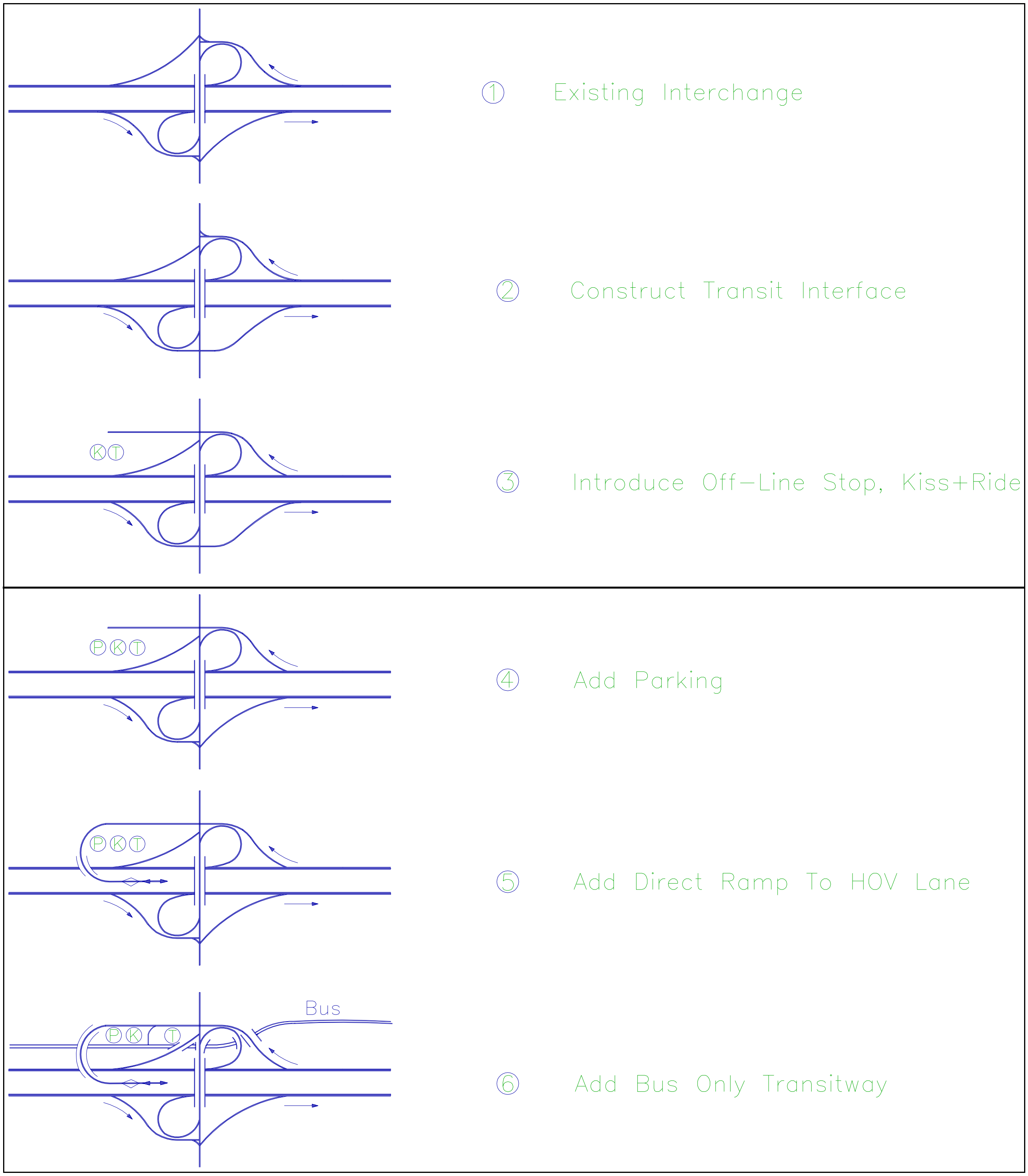


~~Figure 12.11.12 Arterial Bus Bays~~

Exhibit 12CR
Staged Development Transit Station




1 Existing Interchange
2 Construct Transit Interface
K T
3 Introduce Off-line stop, Kiss+Ride
P K T
4 Add Parking
P K T
5 Add Direct Ramp To HOV Lane
P K T
6 Add Bus Only Transitway



~~**Figure 12.11.13 Staged Development Transit Station**~~

12.11.4 Other Design Considerations: Pavement Structure

Guidelines for the design of busway pavements stem from direct experience with the design of flexible and rigid roadway pavement systems. These guidelines are proposed for use in the planning stage only and do not preclude the need for detailed pavement structure design.

Subsequent detailed investigation, necessary before final design, will almost certainly indicate the need for modifications to the typical pavement thickness given in this document. Factors such as design traffic, subgrade conditions, environmental effects, availability of acceptable construction materials, construction traffic, performance of similarly loaded pavements in the area and economics all need to be considered as part of detailed design to arrive at an optimum pavement structure.

Pavement design is directly influenced by the expected number of heavy axle loadings, as opposed to the gross vehicle weight, as multiple axles help spread the load on the pavement and reduce the impact. However, loading is not even across axles, and typically the rear axle on a two-axle vehicle will carry 70 to 75 percent of the gross vehicle weight. Note that even small increases in weight on an axle can cause disproportionately large amounts of damage to the pavement structure.

Typical pavement section depths for a rigid pavement are in the range of 175 to 250 ~~millimeters~~ mm of Portland cement concrete on a 150 ~~millimeter~~ mm deep crushed granular base course. For a flexible pavement, the typical depths are 125 to 175 ~~millimeters~~ mm of asphaltic concrete pavement over 300 to 375 ~~millimeters~~ mm of crushed granular base course. The life cycle of asphalt would include an overlay of 2 inches at approximately 12 to 15 years.

12.11.5 Bus Bypass Shoulder (BBS)

Bus-on-shoulder operations, also known internationally as **"bus bypass shoulder" (BBS)** operations, are a low-cost strategy allowing buses to travel at or near free-flow speeds through congested freeway routes. BBS describes the routing of a bus onto the shoulder of a road~~, usually a highway,~~ in lieu of the standard general-purpose lanes. BBS is a policy-based alternative to constructing dedicated rights-of-way or restricting lane use to high-occupancy vehicles (HOV). The primary goal is to prioritize the reliable performance of public transit over capacity for single-occupant vehicles (SOV). Bus-on-shoulder is typically used only where roadway congestion is severe enough that traveling on the shoulder improves on-time reliability and even decreases overall trip time (~~**Figure**~~

~~**12.11.1**~~**Exhibit 12CS4**).

Safety

Shoulders are generally reserved for emergency vehicle access and to provide a safe haven for disabled vehicles. From a highway operations and safety viewpoint the BBS use operations raise several important concerns. These concerns encompass the loss of basic functions that shoulders are intended to provide (removal and storage of disabled vehicles, emergency vehicle access, and highway maintenance staging), traffic safety risks, and the added costs for maintenance and enforcement.

The traffic safety concerns include:

- Conflicts at on- and off-ramps~~;~~
- Sight distance adequacy, particularly at on-ramps~~;~~
- Conflicts for motorists pulling onto the shoulder~~;~~
- Loss of safe evasive movement shelter area~~;~~
- Need for bus driver training~~;~~
- Speed differential~~;~~
- Impact on adjacent lane motorists~~;~~
- Return merge distance adequacy~~;~~
- Shoulder area debris hazards~~;~~
- Reduced clearance for buses at bridge abutments~~; and~~
- Highway drainage

~~.~~

Visibility around access ramps can be a challenge. Older facilities may have very narrow exits or on-ramps making a challenge both for the bus traveling at high speed and other vehicles entering the highway. -Conflicts with merging traffic on the right shoulder can be averted through ramp metering technology (as done in Vancouver) or by permitting use of the right shoulder only where the bus makes frequent exits and/or on-or-off ramps occur infrequently. In cold climates, the shoulder may be essential for snow storage if it cannot be cleared beyond the paved surface, diminishing the practicality of the bus-on-shoulder service.

Exhibit 12CS

Bus ByPass Shoulders

Source: The Big Move – Metrolinx

~~**Figure 12.11.14 Bus ByPass Shoulders**~~

Exhibit 12CT

Mississauga Transit including Bus ByPass Shoulders on Highway 403~~*Source: The Big Move – Metrolinx*~~

~~**Figure 12.11.15Mississauga Transit including Bus ByPass Shoulders on Highway 403**~~

12.11.5.1 Choosing Corridors for Bus on Shoulders

The concept of bus usage of shoulders is a low-cost solution for relieving buses from the pressures of traffic congestion. Because cost is a constraint, BOS cannot be implemented just anywhere. Only corridors with high levels of bus usage and significant peak period congestion would result in enough benefits to bus riders to warrant costs. Minor improvements to shoulders can be made to accommodate buses, but most of the elements required for bus usage must be in place at the start to make projects non-cost-prohibitive. In the ideal case, a corridor would only need appropriate signage to implement BOS. Many cities that have implemented BOS developed a list of criteria for choosing potential BOS corridors.

A suggested list is as follows:

- There must be predictable congestion delays, meaning the traffic running speed must be less than 55 km/h~~r~~ during the peak period and/or approaches to intersections have continuous backups~~.~~
- Congestion delays must occur one or more days per week~~.~~
- A minimum of six transit buses per day must use the proposed bus shoulder~~.~~
- The expected time savings of using the shoulder must be greater than 5 minutes per kilometer per week~~.~~
- The proposed shoulder must have a continuous shoulder width of at least 3.3 m~~.~~

O. Reg. 618/05: DESIGNATION OF BUS BY-PASS SHOULDERS ON KING'S HIGHWAY, includes the sections of Highways 403, 417, 8 and 401 that are designated as having paved shoulders for use by a bus operated in accordance with a license issued under the *Public Vehicles Act* and an authorization provided by the Ministry.- Refer to O.Reg 618/05 for the signage required on shoulders.

12.11.5.2 Bus Shoulder Lanes

Bus shoulder lanes are authorized bus-only lanes that run along selected freeways. They are a low-cost solution that fully use the capacity of existing corridors and provide immediate benefits to fixed route buses operated by local transit agencies.- Most bus shoulder lanes are on the right shoulder, which allow buses to enter the freeway from the right-side during peak congestion hours and avoid having to weave into either general purpose or HOV traffic.- Bus shoulder lanes are not designed to carry a large amount of traffic and are only used during specific times so buses can maintain a reliable schedule during periods of peak congestion.

Bus shoulder lanes look and operate like any other shoulder and have a minimal effect on traffic in the general purpose or HOV lanes. The shoulder will still be available first for disabled vehicles, incident response and emergency or enforcement situations. The lanes are designed for adequate stopping sight distance with the reduced operating speeds.

Buses using the specified bus shoulder lanes cannot exceed all other traffic by more than 15 mph to ensure safe travel for all corridor users. The maximum speed allowed is 55 k~~K~~m/hr.

All bus drivers traveling in bus shoulder lanes ~~have to~~must yield to all other traffic, including any vehicles entering the shoulder and all motorists in the general purpose or HOV lanes when exiting the shoulder.

Signs alerting non-transit drivers of the potential for buses traveling along the shoulder during designated hours are posted along freeway corridors with bus shoulder lanes. Supplemental "Emergency Stopping Only" signs are located throughout the corridor.

12.11.5.3 Bus Use of Shoulders in HOV Lane Corridors

High-occupancy vehicle (HOV) lanes can be used transit vehicles on freeways and expressways. The HOV lane can be located on either the median side or the outer side of the general-purpose traffic lanes. The operational challenge with use of a median HOV lane is getting buses out of the lane and across the general-purpose traffic lanes to exit.

A possible configuration for longer-distance transit routes is to use existing shoulders on expressways or freeways. This configuration is often referred to as a reserved bus lane (RBL) or bus on shoulders (BOS). BOS typically uses the right-hand shoulder, though left-hand shoulders can also be used for BOS if it is an express-type service.

There are **advantages to placing the Transitway on the shoulders,** including the following:

- Transit vehicles ~~have the ability to~~can enter and exit the shoulder whenever necessary to leave or enter the general-purpose outer traffic lane to maintain operating speed.
- The investment costs to convert a conventional shoulder to a BRT guideway are relatively low, typically limited to upgrading the pavement structure on the

shoulder to accommodate the heavier and more constant use by BRT vehicles and the adjustment of storm water inlets for ride quality.

- Transit vehicles ~~have the ability to~~can exit the freeway without weaving if they are making connections at interchanges.
- Freeway design standards ~~usually~~ typically permit high BRT vehicle operating speeds.

The **disadvantages of having the Transitway on a freeway shoulder** include the following:

- Disabled vehicles on the shoulder require that all transit vehicles re-enter the adjacent general-purpose traffic lane to pass the disabled vehicle.
- Upgrading of the shoulder pavement structure to accommodate the loadings from Transit vehicles may create delays to freeway traffic during construction work, unless there is sufficient room in the median to permit the lanes to be shifted during construction.
- Extra signage and motorist information is required to explain the use of the shoulders by buses.
- Transit vehicles may have to merge into the general-purpose lanes in advance of interchange exits if the bus does not exit at that location.
- Consideration needs to be given in operating policies to possible major speed differentials between buses and other traffic on the adjacent congested general-travel lanes.

It is desired that a Transit vehicle have a~~n~~ 3.5 m (10.5 f~~F~~eet) -wide travel lane with an additional 0.6 m (2 feet) wide paved shy distance between the edge of the running way and any obstructions, piers, sign supports, walls, ditch edges or guiderails, as well as a 0.6 m buffer between the Transit Lane and the adjacent general-purpose lanes. However, in retrofit situations, the dimensions are typically limited by existing adjacent obstructions. Widening of the existing shoulder width to the desired 4.5 m (15 feet) section is not always attainable.

High-occupancy vehicle (HOV) lanes can be used for BRT and other transit vehicles on freeways and expressways. The HOV lane can be located on either the median side or the outer side of the general-purpose traffic lanes. The operational challenge with use of a median HOV lane is getting buses out of the lane and across the general-purpose traffic lanes in order to exit.

The pavement structure of the existing median or shoulder should be reviewed carefully to ensure that it can accommodate the additional loads from the BRT.

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