# HOV Direct Access

## Design Guide

**M 22-98**

**April 1998**

DRAFT

Washington State Department of Transportation

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# Foreword

This publication is guidance for the design of highway facilities that provide direct access for high occupancy vehicles (HOVs) between HOV lanes and flyer stops and other public-transportation passenger facilities.

The Washington State Department of Transportation provides guidance for the design of right-side access facilities in the *Design Manual* (M 22-01). This publication supplements the *Design Manual* with guidance for the design of left-side access facilities and other HOV access facilities with extremely limiting width constraints.

The guidance and full design level in the *Design Manual* are to be used where applicable. This publication provides additional guidance for consistent designs of HOV direct access facilities.

DONALD K. NELSON
State Design Engineer

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# 1

# General

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1.02 Existing Facilities
1.03 Deviations
1.04 Reviews, Studies, and Reports

## 1.01 This Guide

This publication is a supplement to the *Design Manual* providing guidance for the design of direct access facilities for high occupancy vehicles between HOV lanes and public-transportation passenger facilities.

The Washington State Department of Transportation provides guidance for the design of highways in general, and right-side access facilities in particular, in the *Design Manual*. This draft guide supplements the *Design Manual* with guidance for the design of facilities to fit into extremely limited spaces, left-side direct access facilities, and other HOV access facilities specifically to accommodate buses.

Use this publication as an extension of the *Design Manual* when designing HOV direct access facilities and request approval of a deviation for any decision to do more or less than indicated. This guide provides for consistent designs of features not found in the *Design Manual*. For example, the left-side parallel on-connection design presented here is a new design not covered in the *Design Manual*.

## 1.02 Existing Facilities

When designing an HOV direct access facility, the existing general purpose facilities must not be degraded. However, there may be opportunities to improve existing geometrics. These opportunities can be identified during the project definition phase.

When an HOV direct access facility project includes work on the existing facilities of the Interstate, apply the new/reconstruction row of the Interstate Design Matrices in *Design Manual* Chapter 325, “Design Matrix Procedures,” and process deviations accordingly.

## 1.03 Deviations

When designing an HOV direct access facility, an approved deviation is required for any left-side connection.

Approval of a deviation must be sought in accordance with *Design Manual* Figure 330-1, "Design Approval Level," in Chapter 330, "Design Documentation and Approval." When applying for deviation approval, it is necessary to provide two explanations. The first explains why the WSDOT guidance was not or could not be used. The second provides the justification for the design that is proposed. Justification for a deviation must be supported by at least two of the following:

- Accident history or potential
- Benefit/cost analysis
- Engineering judgment
- Environmental issues
- Route continuity

Engineering judgment justification might include references to other publications.

## 1.04 Reviews, Studies, and Reports

The *Design Manua*l is to be followed when developing an HOV direct access project. Most facets of the project development process remain unchanged despite the unusual nature of the projects that are the focus of this guide. For example, early coordination with others is always a vital part of developing a project. There are also environmental considerations, public involvement, and Value Engineering studies. These are all necessary to ensure appropriate scope and costs.

There may also be reviews, studies, and reports required by agreements with regional transit authorities or other agencies.

Use *Design Manual* Chapter 1425, "Access Point Decision Report," when there is a proposal to add, delete, or change an access point.

Use *Design Manual* Chapter 315, "Value Engineering" (VE), to conduct VE studies that:

- Reduce impacts.
- Analyze functions.
- Reduce project costs.
- Ensure coordination with internal and external partners.
- Define scope.

Throughout the project development phase, ensure that the:

- Project definition and cost estimate are correct.
- Project development process is on schedule.
- Project documents are biddable.
- Project will be constructible.
- Project will be maintainable.

Constructibility of HOV direct access facilities is an important consideration during the design phase. These facilities will typically be constructed on existing highways with traffic maintained on-site. Key goals are to:

- Ensure that the project can be built.
- Plan a construction strategy.
- Provide a safe work zone.
- Minimize construction delays.

Access to these facilities by maintenance crews must be considered. Avoid items that require a significant maintenance effort and might result in lane closure for routine maintenance or repair.

# 2

# References

2.01 General
2.02 References

## 2.01 General

There are several excellent publications that might be useful for the planning, design, and operation of high occupancy vehicle facilities. The references listed below are only a select few and there will, no doubt, be new ones after this guide is published.

This guide has several figures that have been copied from Parsons Brinkerhoff Inc. publications with their permission and valuable assistance.

## 2.02 References

- ***Design Manual*** M 22-01
- ***Manual on Uniform Traffic Control Devices for Streets and Highways and the Modifications for Washington State*** (MUTCD) M 24-01
- ***Sign Fabrication Manual*** M 55-05
- ***Standard Plans for Road, Bridge, and Municipal Construction*** (Standard Plans) M 21-01
- ***Traffic Manual*** M 51-02
- Northwest Region's ***SC&DI Design Guide***

  Washington State Department of Transportation
  Engineering Publications
  PO Box 47400
  Olympia WA 98504-7400
  (360) 705-7430
- ***High-Occupancy Vehicle Facilities***
  ***A Planning, Design, and Operation Manual***
- ***FHWA/PB HOV Interactive 1.0 High Occupancy Vehicle Data Base from the U.S., Canada and Europe*** (CD ROM)

  Federal Highway Admin. and Parsons Brinkerhoff Inc.
  505 South Main Street, Suite 900
  Orange CA 92668
  (714) 973-4880

- ***A Policy on Geometric Design of Highways and Streets 1994*** (the Green Book)
- ***Guide for the Design of High Occupancy Vehicle Facilities***

  American Association of State Highway
  and Transportation Officials (AASHTO)
  444 North Capitol Street NW Suite 249
  Washington DC 20001
  (202) 624-5800

- ***Transit Implications of HOV Facility Design***
  WA-RD 396.1

  Final Technical Report
  September 1996
  Washington State Department of Transportation in
  cooperation with the USDOT Federal Transit Administration
  National Technical Information Service
  Springfield VA 22616

- ***Bus Use of Highways, Planning and Design Guidelines***
  **Report 155**
- ***HOV Systems Manual***
  draft dated February 1998

  National Cooperative Highway Research Program
  Transportation Research Board
  National Academy of Sciences
  2101 Constitution Avenue NW
  Washington DC 20418

- ***Introduction to Value Engineering***

  Transportation Partnership in Engineering Education
  Development (TRANSPEED), University of Washington
  101B More Hall, FX-10
  Seattle WA 98195

# 3

# Definitions

3.01 General
3.02 Definitions

## 3.01 General

The following definitions are mainly from AASHTO's *Transportation Glossary* but some have been customized or created for this publication.

## 3.02 Definitions

**flyer stop** a transit stop inside the limited access boundaries

**HOV** high occupancy vehicle, a motor vehicle carrying a sufficient number of passengers to qualify for occupying a lane which is reserved for movement of a large number of people

**HOV direct access facility** a ramp and its connection directly to an HOV lane, exclusively for the use of high occupancy vehicles to move between the ramp and the HOV lane without crossing general purpose lanes

**ramp** a short roadway connecting a main lane of a highway with another facility for vehicular use, such as a road, parking lot, or transit stop

**ramp connection** the pavement at the end of a ramp, connecting to a main lane of a highway

**ramp terminal** the end of a ramp at a local road, transit stop, or park and ride lot

**SC&DI** surveillance, control, and driver information, a system designed to optimize efficiency of a transportation network by collecting traffic data, controlling access, and relaying information

**transit stop** a facility for loading and unloading passengers that is set aside for the use of transit vehicles only

**transit vehicle** a bus or other motor vehicle that provides public transportation (usually operated by a public agency)

# 4

# HOV Access Types and Locations

4.01 General
4.02 Freeway Connection Locations
4.03 Ramp Terminal Locations
4.04 Ramp Types
4.05 Transit Stops
4.06 Enforcement Areas

## 4.01 General

To provide direct access for high occupancy vehicles from the HOV lane to a passenger loading facility, there are many options and many constraints. This chapter describes a select few of the options (selected as being considered useable on Washington's freeways) and focuses on some of the constraints.

To select an option, it is necessary to first establish the need, choose possible locations, evaluate site features (such as terrain, existing structures, median widths), and evaluate existing HOV information (such as lanes, park and ride facilities, transit routes and schedules, and origin and destination studies). The chosen location must meet access point spacing requirements and must be proven not to degrade traffic operations on the main line.

Important constraints to transit stop designs are that passenger access to a bus is on its right side only and passenger access to a loading platform must accommodate the disabled.

## 4.02 Freeway Connection Locations

### (1) Spacing

For minimum ramp terminal spacing see *Design Manual* Chapter 940, "Traffic Interchanges." Include general purpose ramp connections that cause traffic to cross the HOV lane, as well as the HOV direct access connections, in this evaluation. General purpose ramps that do not cause traffic to cross the HOV lane are not considered when evaluating the spacing of the HOV direct access connections.

However, traffic operations can be degraded by the weaving caused by a left-side on-connection followed closely by a right-side off-connection (or a right-side on-connection followed by a left-side off-connection). Conduct an analysis to ensure that the new ramp will not degrade traffic operations. See *Design Manual* Chapter 1425, "Access Point Decision Report," for guidance on the studies and report required for a new access point to be considered on the Interstate system.

When an off-connection follows an on-connection, provide full speed-change lane lengths and tapers (Chapter 5, "Direct Access Geometrics") or at least sufficient distance for full speed-change lanes that connect at full width (no tapers). An auxiliary lane can be used to connect the full-width speed-change lanes if there is not sufficient distance for both tapers.

### (2) Sight Distance

Locate both on- and off-connections to the main line where decision sight distance exists on the main line. (See *Design Manual* Chapter 650, "Sight Distance.")

## 4.03 Ramp Terminal Locations

### (1) Local Roads

Access to the HOV lane can be provided by a ramp that terminates at an intersection with a local road. The local road may incorporate HOV lanes, but they are not required. See guidance in Chapter 7, "Traffic Design Elements," for signing (and pavement markings in the figures).

Consider traffic operations on the local road. Locate the terminal where:

- It will have the least impact on the local road.
- Intersection spacing requirements are satisfied.
- Queues from adjacent intersections will not block the ramp.
- Queues at the ramp will not block adjacent intersections.
- Wrong way movements are discouraged.

When off ramps and on ramps are opposite each other on the local road, consider incorporating a transit stop with the intersection.

### (2) Park and Ride Lots

Direct HOV access ramps that connect the HOV lane with a park and ride lot provide easy access for express transit vehicles between the HOV lane and a local service transit stop at the park and ride facility. Other HOV traffic using the access ramp must enter through the park and ride lot.

### (3) Flyer Stops

Median flyer stops do not provide general access to the HOV lane. Access is from the HOV lane to the transit stop and back to the HOV lane. No other vehicle access is provided. Ramps to and from the flyer stops are normally for transit vehicles only.

## 4.04 Ramp Types

### (1) Drop Ramps

Drop ramps are generally straight, staying in the median, and connecting the HOV lane with a local road or flyer stop (Figure 4-1).

### (2) T Ramps

A T ramp is a median ramp, serving all four directions, that comes to a T intersection within the median, usually on a structure. The structure then carries the HOV ramp over part of the freeway on a local road or directly to a park and ride lot (Figure 4-2). Through traffic is not permitted at the T.

### (3) Flyover Ramps

A flyover ramp is designed to accommodate high speed traffic by using flat curves as the ramp crosses from the median over one direction of the freeway to a local road, a park and ride lot, or an HOV lane on another freeway (Figure 4-3).

## 4.05 Transit Stops

### (1) Flyer Stops

Flyer stops are transit stops inside the limited access boundaries for use by express transit vehicles using the freeway. They may be located in the median at the same grade as the main roadway or on a structure, on a ramp, or on the right.

The advantage of a flyer stop is that it reduces the time required for express transit vehicles to serve intermediate

destinations. A disadvantage is that passengers must travel greater distances to reach the loading platform.

See *Design Manual* Chapter 1060, "Transit Benefit Facilities," for additional design information.

(a) **Side-Platform Flyer Stops** Side-platform flyer stops are normally located in the median (Figure 4-4) and have two passenger loading platforms, one on each side between the bus loading lane and the through HOV lane. This design provides the most direct movement for the express transit vehicle and is the preferred design for median flyer stops.

This design is relatively wide. Where space is a concern, consider staggering the loading platforms longitudinally.

Consider tall barrier to divide the directions of travel or staggering the loading platforms to prevent unauthorized at-grade movement of passengers from one platform to the other. (See 7.02 Traffic Barriers in Chapter 7, "Traffic Design Elements.")

(b) **Center-Platform Flyer Stops** Center-platform flyer stops are normally located in the median (Figure 4-5) and have a single passenger loading platform between the bus loading lanes. With this design, less median width is needed than for a side platform flyer stop and transfers are easier. Because of the crossover of the lanes, only transit vehicles are allowed.

Use geometrics, positive guidance, signing, etc., when designing the crossovers, to minimize wrong way traffic.

Use gates at the entrances to keep unauthorized vehicles from entering. (See 7.02 Traffic Barriers in Chapter 7, "Traffic Design Elements.")

(c) **At-Grade Passenger Crossings** This design is similar to the side-platform flyer stop, except that passengers are allowed to cross from one platform to the other at grade (Figure 4-6). This design might eliminate need for elevated passenger access to one of the loading platforms and simplifies transfers. The passenger crossing necessitates providing a gap in the barrier for the crosswalk.

Only transit vehicles are allowed.Consider signals as discussed in 6.02 "Passengers," Chapter 6, "Passenger Access."

(d) **Ramp Flyer Stops** A flyer stop on a right-side ramp works well with diamond interchanges in which express transit vehicles can use the off-ramp to connect with a bus route on the local road and the on-ramp to return to the HOV lane. When located on an HOV direct access drop ramp (Figure 4-7), the delay for the express transit vehicle will not be much more than that for a median stop, and passenger access and connectivity to local service transit routes on the local road are improved. A stop on a general purpose ramp will increase the delay by requiring the express transit vehicle to use the general purpose lanes and possibly degrade main line traffic operations by increasing weaving movements.

(e) **Other Flyer Stops** With left side HOV lanes, flyer stops located on the right side will increase the delay to the express transit vehicles by requiring them to cross the general purpose lanes. However, these stops improve passenger access from that side of the freeway.

### (2) Off-Line Transit Stops

(a) **Park and Ride Stops** Transit stops located at park and ride lots provide transfer points between the express transit system and the local transit system, and there is convenient passenger access to the park and ride lot. When a direct access ramp is provided, express transit delays from the HOV lane to the stop are reduced. These delays can be reduced more by providing a median flyer stop with passenger access facilities connecting the park and ride lot to the flyer stop.

(b) **Flyer stop passenger access points** To minimize the distance a passenger must travel between express and local service transit stops, locate local system transit stops near passenger access facilities for the flyer stops (Figure 4-8).

## 4.06 Enforcement Areas

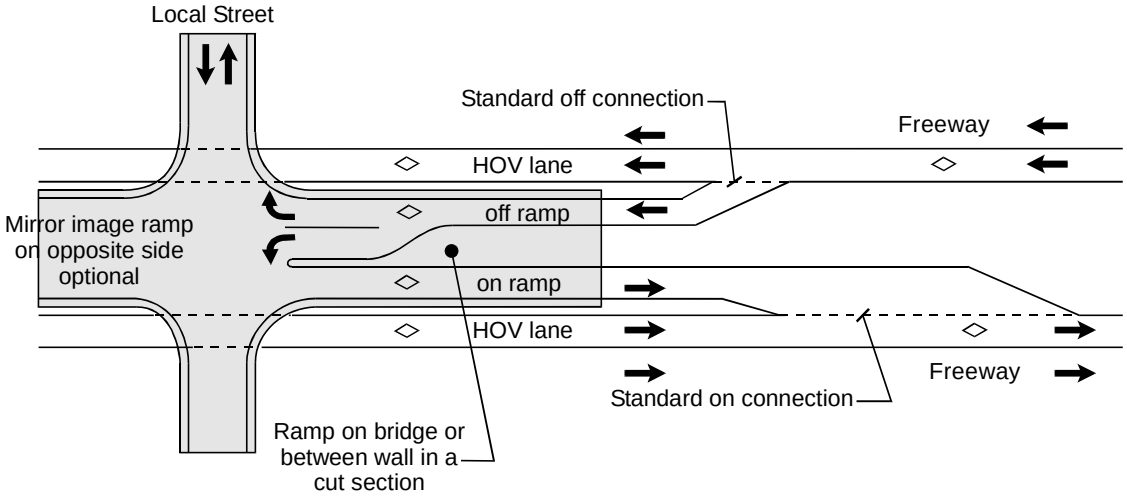
For HOV facilities to function as intended, it is necessary to enforce the vehicle occupancy requirement. Law enforcement officers need areas for observation that are near pull-out areas where both the violator and the officer can pull safely out of the traffic flow.

Consider locating observation and pull-out areas near any point where violators can enter or exit an HOV direct access facility. Examples of potential locations are:

- Freeway on- and off-connections for HOV direct access ramps.
- HOV direct access ramp terminals at parking lots.

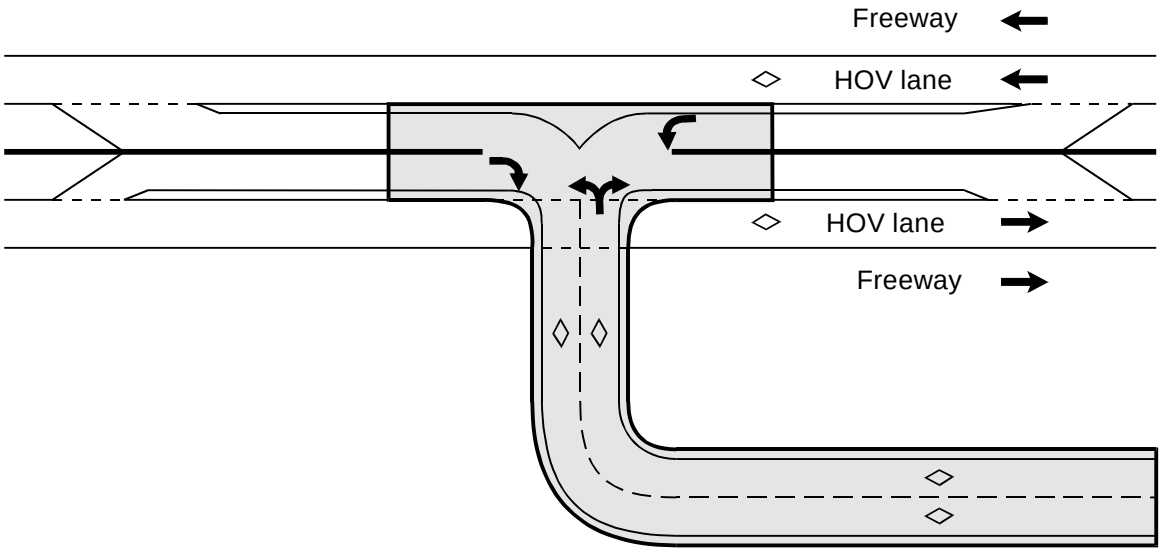
For freeway HOV lanes, locate enforcement areas on the adjacent shoulders so officers and violators are not required to cross several lanes of traffic.

Guidance and designs are in *Design Manual* Chapter 1050, "High Occupancy Vehicle Priority Treatment."

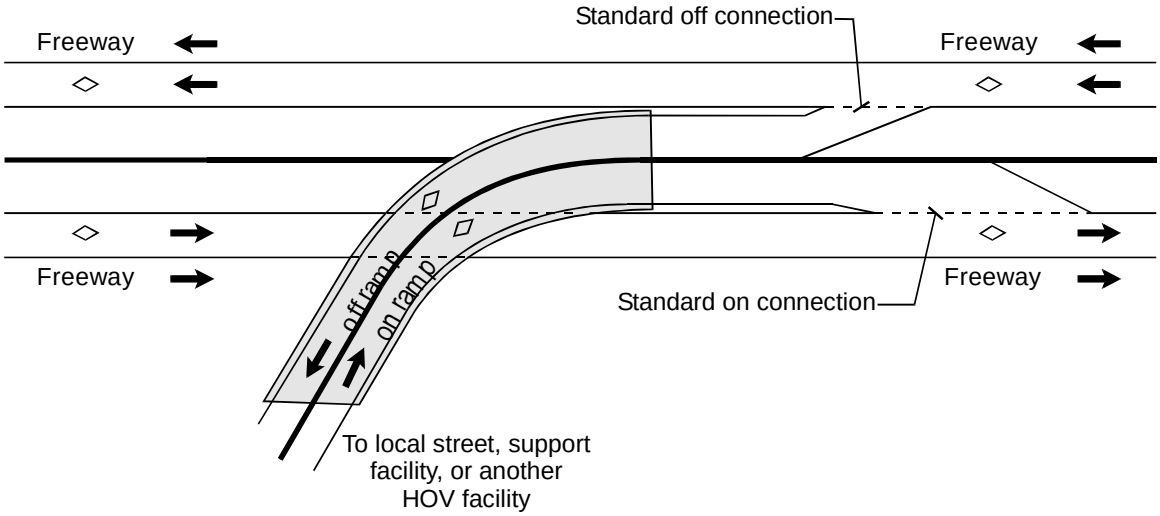



Photograph from *FHWA/PB HOV Interactive 1.0 High Occupancy Vehicle Data Base from the U.S., Canada and Europe*

**Drop Ramp**
**Figure 4-1**

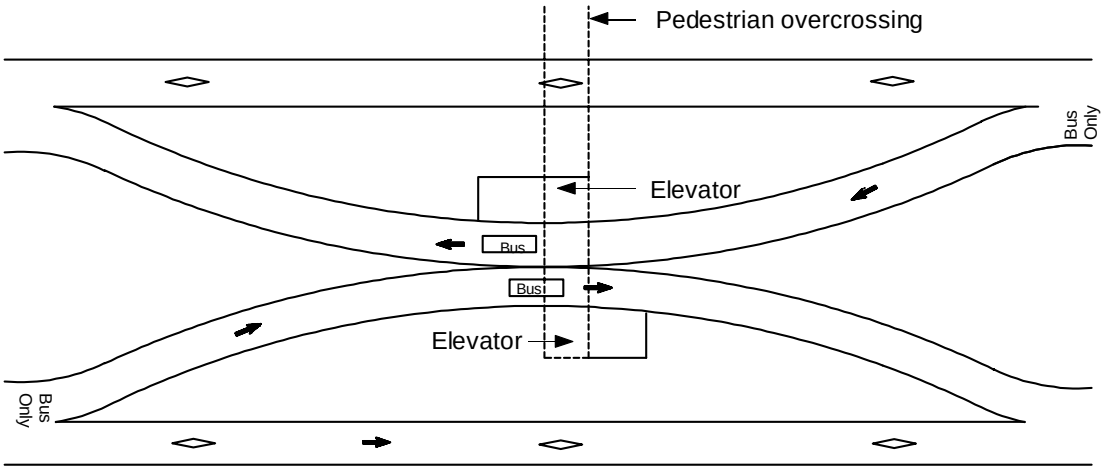



**T Ramp**
**Figure 4-2**



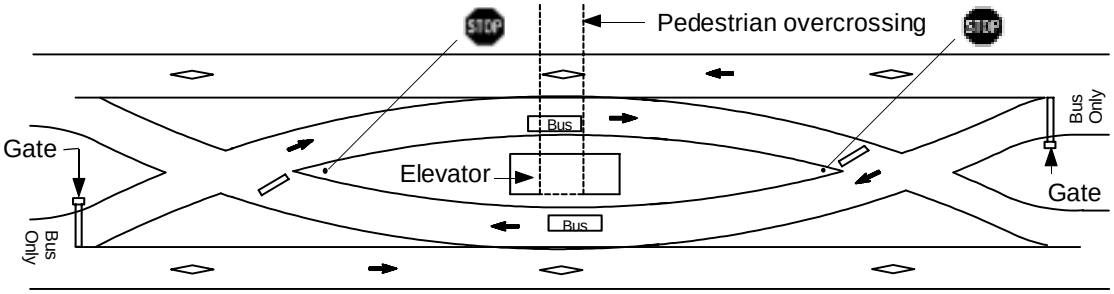

Photograph from *FHWA/PB HOV Interactive 1.0 High Occupancy Vehicle Data Base from the U.S., Canada and Europe*

**Flyover Ramp**
**Figure 4-3**

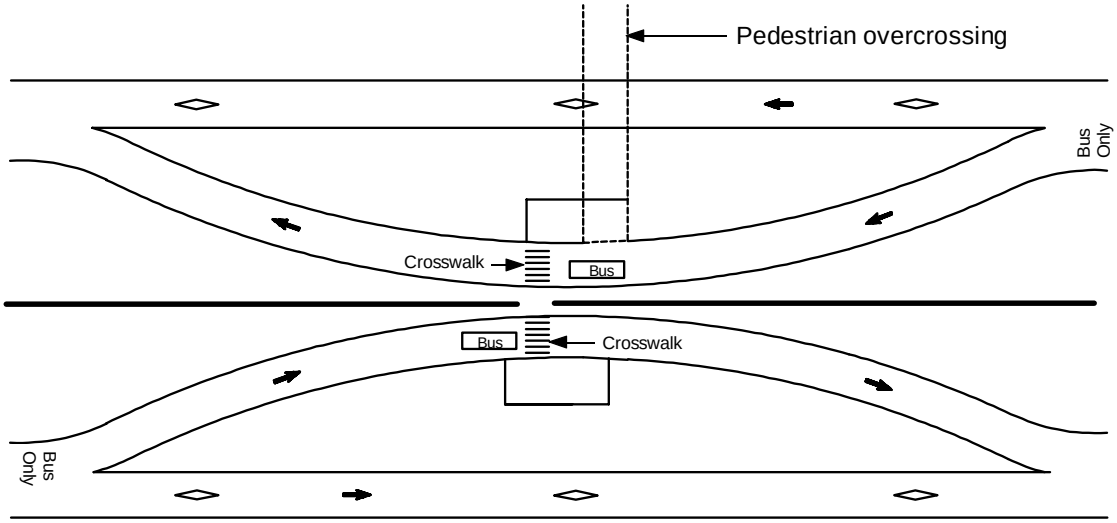



Photograph from *FHWA/PB HOV Interactive 1.0 High Occupancy Vehicle Data Base from the U.S., Canada and Europe*

**Side Platform Flyer Stop**
**Figure 4-4**

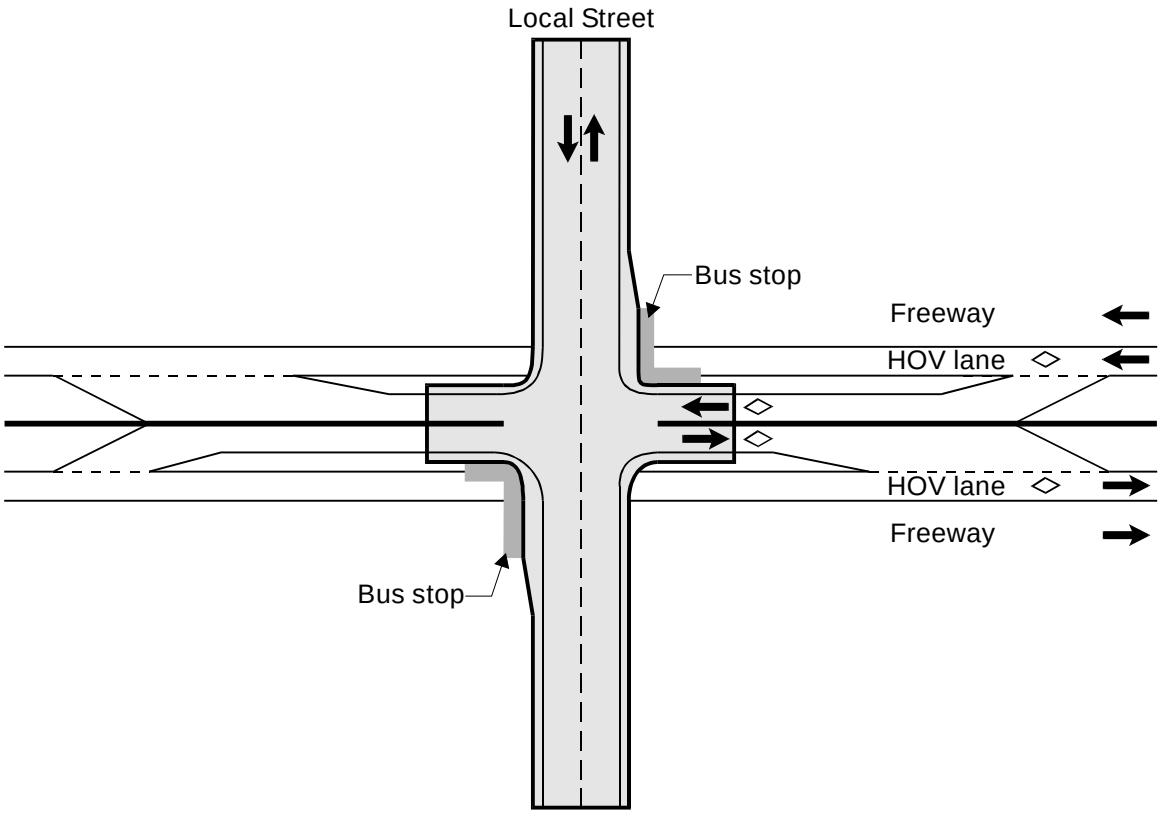



**Center Platform Flyer Stop**
**Figure 4-5**

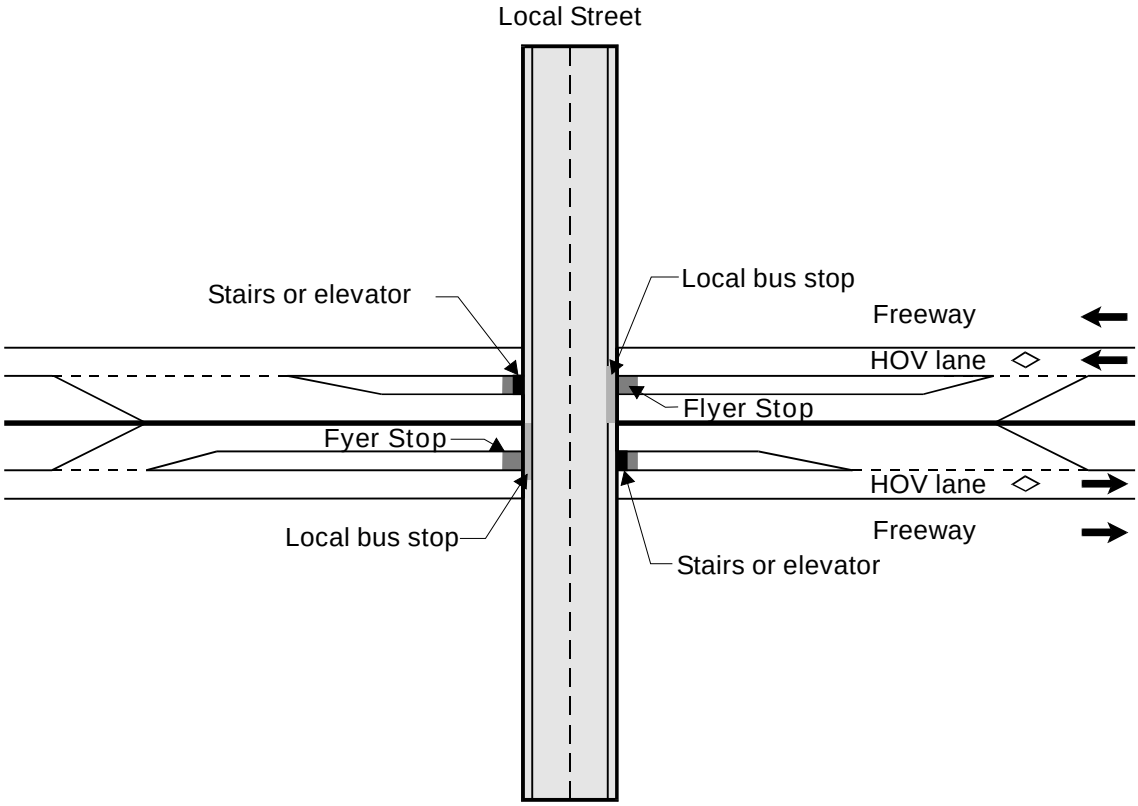


Photograph from *FHWA/PB HOV Interactive 1.0 High Occupancy Vehicle Data Base from the U.S., Canada and Europe*

**At Grade Crossing Flyer Stop**
**Figure 4-6**




**Transit Stops at Ramps**
**Figure 4-7**




**Other Transit Stops**
**Figure 4-8**

# 5

# Direct Access Geometrics

5.01 General
5.02 Design Vehicles
5.03 Design Speeds
5.04 Sight Distance
5.05 Grades
5.06 Ramp Widths
5.07 On-Connections
5.08 Off-Connections
5.09 Vertical Clearance
5.10 Flyer Stops
5.11 T Ramps
5.12 Documentation

## 5.01 General

This chapter covers geometrics of freeway access for the exclusive use of high occupancy vehicles (HOVs). Use *Design Manual* Chapter 940, "Traffic Interchanges," for the design of all other types of ramps. For information on locating access points see 4.02(1) Spacing in Chapter 4 of this guide.

HOV direct access ramps are different from other ramps because they are frequently on the left side of the through lanes and they have a high percentage of buses.

Left side ramps require an approved deviation. Also, because they are rare and are therefore less expected, signing is an important issue.

When the bus percentage is high, there are several needs to be met.

- When a bus enters the through lanes from the left, the driver has a relatively poor view of the through traffic that might be improved with the use of rear-view mirrors if the on-connection is parallel rather than tapered.
- A bus takes longer to accelerate than other vehicles.
- A bus requires longer deceleration for passenger comfort.

For these reasons, use the design values shown in this chapter when designing HOV direct access facilities or request approval of a deviation.

## 5.02 Design Vehicles

Use AASHTO's A-BUS vehicle for horizontal design.

Use AASHTO's BUS vehicle for vertical clearance (4.1 m).

Use AASHTO's P vehicle for stopping sight distance.

See *Design Manual* Chapter 910 and 1060 for vehicle descriptions, dimensions, and turning templates.

## 5.03 Design Speeds

Use *Design Manual* Chapter 940, "Traffic Interchanges," for the normal design speeds for the ramps.

## 5.04 Sight Distance

Provide stopping sight distance per *Design Manual* Chapter 650, "Sight Distance." This provides sight distance for an automobile. The longer distance required for a bus to stop is compensated for by the greater eye height of the driver with the resulting vertical curve length requirement about equal to that for an automobile.

Sag vertical curves may be shortened where necessary with:

- An approved deviation.
- Continuous illumination.
- Design for the comfort of the vehicle occupants. For comfort use:

  $$L = \frac{AV^2}{153}$$

  where: L = Curve length m
  A = Change in grade %
  V = Design speed mph

These minimum lengths are about 50% of those required for sag vertical sight distance.

## 5.05 Grades

Grades for ramps are covered in *Design Manual* Chapter 940, "Traffic Interchanges." With an approved deviation, the following would be allowed:

- Downgrades for on-ramps may be increased by an additional 1%.
- Upgrades for off-ramps may be increased by an additional 2%.

These increased grades help when geometrics are restricted and assist transit vehicles with the acceleration of entering and the deceleration of exiting.

## 5.06 Ramp Widths

### (1) Lane Widths

Use ramp lane widths as given in *Design Manual* Chapters 940, "Traffic Interchanges," and Chapter 640, "Geometric Cross Sections."

On tangents, the minimum ramp lane width may be reduced to 3.6 m.

### (2) Shoulder Widths

Ramp shoulder width requirements are modified (no deviation required) as follows:

- The minimum width for the sum of the two shoulders is 3.0 m for one-lane ramps and 3.6 m for two or more lanes.
- One of the shoulders must have a width of at least 2.4 m for disabled vehicles. The minimum for the other shoulder is 0.6 m.
- The wider shoulder may be on the left or the right as needed to best match the terminals. Maintain the wide shoulder on the same side throughout the ramp.

### (3) Total Ramp Widths

Make the total width of the ramp (lane width plus shoulders) wide enough to allow an A-BUS to pass a stalled A-BUS. This width has two components:

- The vehicle width (U = 2.6 m on tangent) for each vehicle
- Lateral clearance (C = 0.6 m) for each vehicle

The vehicle width and the lateral clearance are about the width of an A-BUS from edge of mirror to edge of mirror.

Figure 5-1 gives the minimum ramp width ($W_R$) at various radii (R) for an articulated bus. For ramp locations on a tangent section or on a curve with a radius greater than 100 m, consider the $W_R$ width when requesting a reduced lane or shoulder width. For ramp curves with a radius less than 100 m, check the total ramp width and, if necessary, widen the shoulders to provide the $W_R$ width.

| R (m) | $W_R$ (m) |
|---|---|
| Tangent | 6.4 |
| 150 | 6.9 |
| 125 | 6.9 |
| 100 | 7.5 |
| 75 | 7.8 |
| 50 | 8.4 |
| 30 | 9.0 |
| 25 | 9.6 |
| 15 | 11.1 |

**Minimum Ramp Widths for Articulated Buses Figure 5-1**

In this table, $W_R$ exceeds *Design Manual* values where R is 100 or less.

## 5.07 On-Connections

### (1) Tapered On-Connections

For right-side on-connections, use the tapered design. See *Design Manual* Chapter 940, "Traffic Interchanges," for the design of tapered on-connections.

A tapered on-connection enters the main line with a long, uniform taper. For right-side on-connections, the entering driver can see gaps in the through traffic and use them by adjusting the vehicle's speed.

Do not use a tapered on-connection on the left side.

### (2) Parallel On-Connections

For left side on-connections, use the parallel on-connection. See Figure 5-3. The use of a parallel on-connection on the right requires justification.

A parallel on-connection requires less width at the connection with the main line. It adds a parallel lane that is long enough for the merging vehicle to accelerate in the lane and then merge with the through traffic. This merge is similar to a lane change and the driver can use side and rear view mirrors to advantage.

### (3) Acceleration Lanes

Figure 5-4 gives the LA length for left-side HOV direct access on-connections. The minimum lengths for acceleration lanes are shown in *Design Manual* Chapter 940, "Traffic Interchanges."

The numerous buses using HOV direct access ramps must merge with high speed traffic. Acceleration lanes that are longer than normally required are needed.

For left-side on-connections, provide at least the normal 3.0 m (4.2 m preferred) wide left shoulder for the main line for a minimum length of 150 m (300 m preferred) beyond the end of the on-connection taper. This gives additional room for enforcement, merging, and erratic maneuvers.

### (4) Gap Acceptance Length

Gap acceptance length is a minimum distance traveled while a merging driver finds a gap in the through traffic and begins the merge. The gap acceptance length is measured concurrently with the acceleration length when on the right. When on the left, add the two lengths.

When designing a left-side parallel on-connection, increase the $L_g$ values (Figure 5-3) to those given in Figure 5-2 to account for drivers' visibility constraints.

Minimum gap acceptance length ($L_g$) for a parallel on-connection is given on Figure 5-3.

For a right-side tapered on-connection, the 50:1 taper will provide the minimum length.

| Highway Posted Speed (mph) | Gap Acceptance Length (m) |
|---|---|
| 45 | 165 |
| 50 | 190 |
| 55 | 210 |
| 60 | 235 |
| 65 | 255 |
| 70 | 280 |

**Gap Acceptance Length for Parallel On-Connections Figure 5-2**

## 5.08 Off-Connections

### (1) Tapered Off-Connection

The tapered off-connection is preferred for both left and right side off-connections. See *Design Manual* Chapter 940, "Traffic Interchanges," for the design of tapered off-connections.

### (2) Parallel Off-Connection

The parallel off-connection (Figure 5-5) requires less width at the connection with the main line. Use a tapered off-connection unless a parallel design can be justified.

### (3) Deceleration Lanes

Bus passenger comfort requires longer deceleration lanes. Use the deceleration lane lengths from Figure 5-6 for HOV direct access facilities. The minimum length deceleration lanes are shown in *Design Manual* Chapter 940, "Traffic Interchanges."

## 5.09 Vertical Clearance

Vertical clearance for a structure over a road is measured from the lower roadway surface, including the useable shoulders, to the bottom of the overhead structure.

For a new structure, widening an existing structure, and for a new ramp under an existing structure, the minimum vertical clearance is 5.0 m. With an approved deviation:

- 4.9 m is the minimum vertical clearance for widening an existing bridge over an Interstate highway.
- 4.7 m is generally considered the minimum for widening an existing bridge over a non-Interstate highways.
- 4.4 m is the minimum vertical clearance for a new HOV direct access ramp under an existing bridge.

The minimum vertical clearance for a pedestrian grade separation over any road is 5.35 m.

## 5.10 Flyer Stops

Design flyer-stop-ramp on-connections as shown in 5.07 On-Connections, and design off-connections as shown in 5.08 Off-Connections. Flyer stop connections are included in the access point spacing discussed in 4.02(1) Spacing.

Design the ramp to the flyer stop per sections 5.04 Sight Distance, 5.05 Grades, and 5.06 Ramp Widths.

The minimum width for the roadway at a flyer stop depends on the usage. When it is expected that only one bus at a time will be at the stop, the minimum width is 6.4 m. When more than one bus at a time will be using the stop, the minimum width is 7.2 m.

When a flyer stop is in the median, provide enough space between the flyer stop roadway and the through lanes for the full left-side shoulder (for the through lanes) and for the passenger facilities. (See Chapter 6, "Passenger Access.")

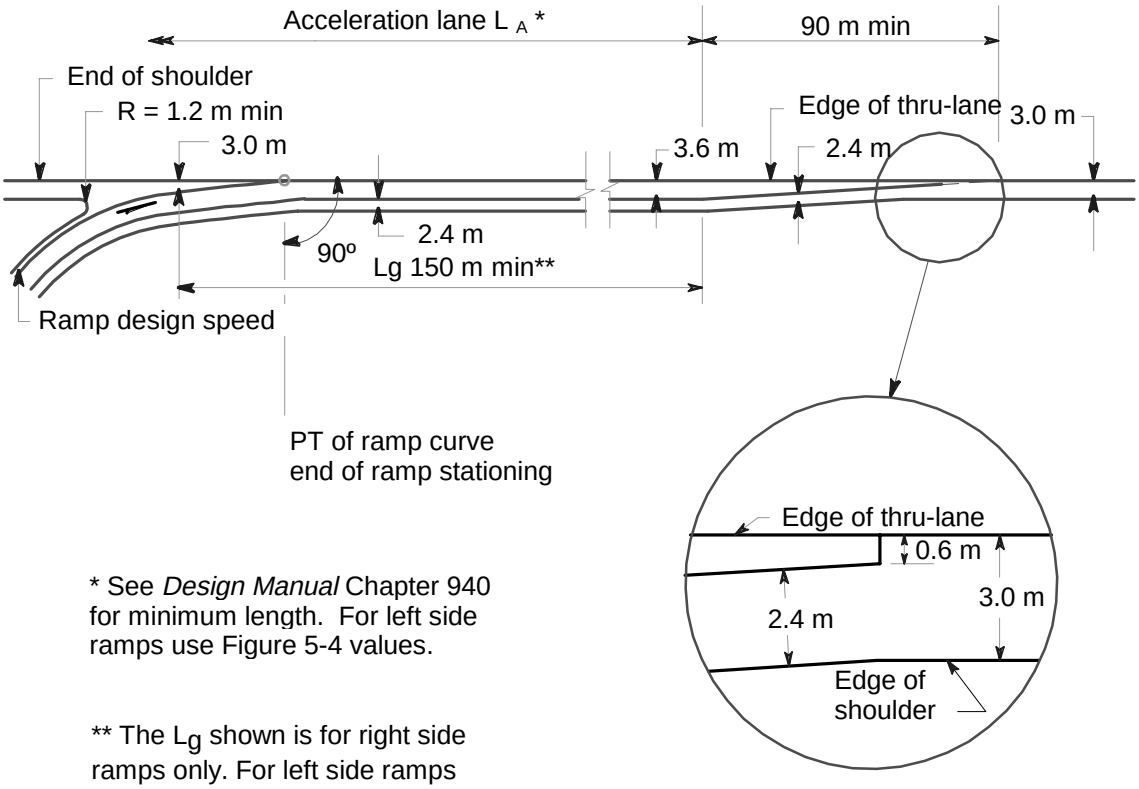
## 5.11 T Ramps

Examples of some T ramps and design guidelines are given on Figure 5-7

## 5.12 Documentation

The following documents are to be preserved in the project file:

- ☐ Justification for use of a parallel on-connection on the right.
- ☐ Justification for use of a parallel off-connection.




* See *Design Manual* Chapter 940 for minimum length. For left side ramps use Figure 5-4 values.

** The $L_g$ shown is for right side ramps only. For left side ramps use $L_g$ values given in Figure 5-2. When the acceleration lane $L_A$ ends after the indicated start of the $L_g$, add $L_g$ to the acceleration lane.

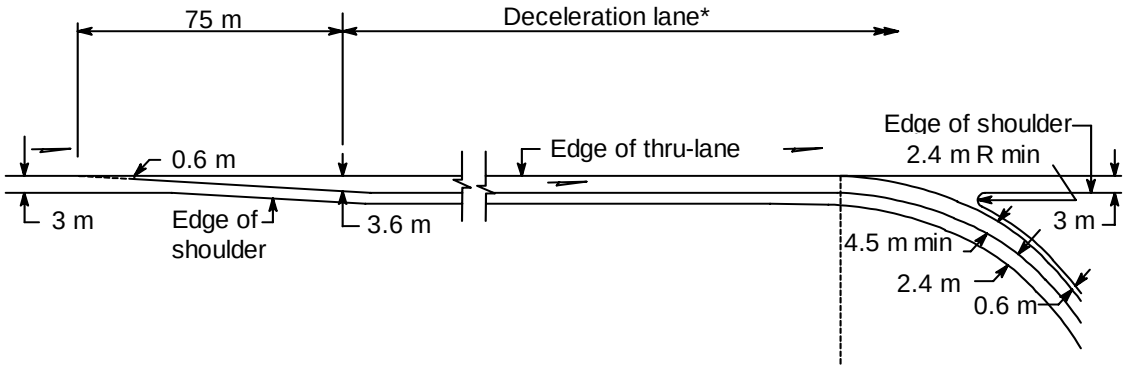
**Single Lane Parallel On-Connection**
**Figure 5-3**

| Freeway Design Speed (mph) | Ramp Design Speed | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 40 | 170 | 150 | 130 | 105 | 55 | | | | |
| 45 | 255 | 235 | 215 | 190 | 145 | 90 | | | |
| 50 | 375 | 355 | 335 | 310 | 265 | 210 | 95 | | |
| 60 | 650 | 640 | 625 | 605 | 575 | 530 | 440 | 305 | 140 |
| 70 | 930 | 920 | 910 | 900 | 875 | 840 | 755 | 625 | 465 |
| 80 | 1375 | 1360 | 1350 | 1335 | 1295 | 1250 | 1145 | 1010 | 850 |

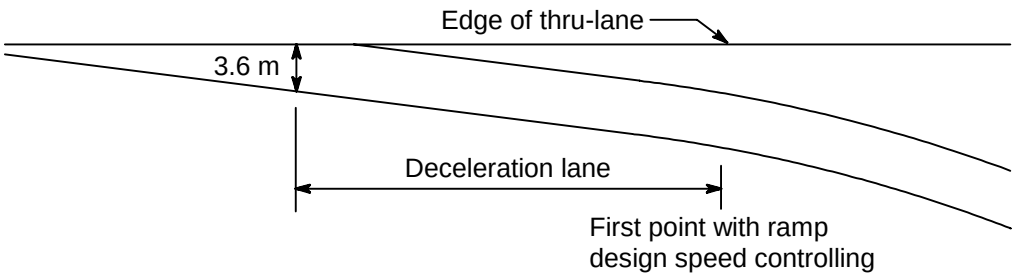
**Acceleration Length for Buses ($L_A$)**
**in meters**

For the adjustment factors for grade, see Acceleration lane length in *Design Manual* Chapter 940, Traffic Interchanges.

**HOV Direct Access**
**Acceleration Lane Length**
**Figure 5-4**




**Single Lane Parallel Off-Connection**
**Figure 5-5**

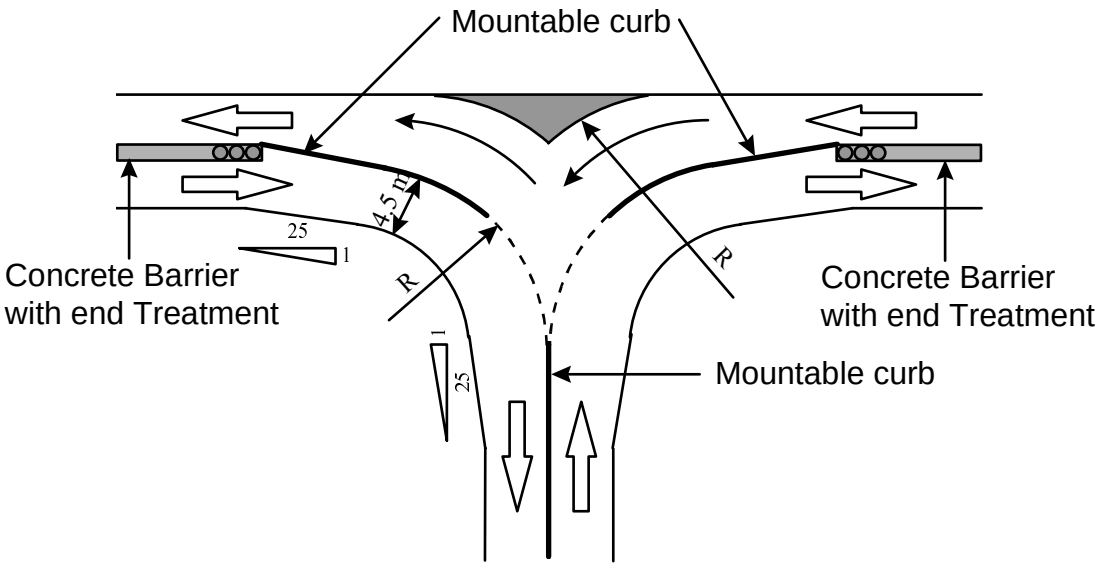



| Highway Design Speed (mph) | Ramp Design Speed (mph) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 40 | 120 | 100 | 90 | 75 | 55 | 30 | | | |
| 45 | 145 | 130 | 115 | 100 | 80 | 60 | 30 | | |
| 50 | 175 | 160 | 145 | 130 | 110 | 90 | 60 | 35 | |
| 60 | 245 | 225 | 215 | 200 | 180 | 160 | 130 | 100 | 70 |
| 70 | 305 | 285 | 275 | 260 | 240 | 215 | 185 | 160 | 130 |
| 80 | 370 | 350 | 340 | 325 | 305 | 285 | 255 | 225 | 195 |

**Deceleration Length for Buses (m)**

For the adjustment factors for grade, see deceleration lane length in *Design Manual* Chapter 940, Traffic Interchanges.

**Deceleration Lane Length**
**for Buses**
**Figure 5-6**




| Design Speed (mph) | Superelevation Rate | | |
|---|---|---|---|
| | -2% | 0% | 2% |
| 15* | 16 | 15 | 14 |
| 20 | 33 | 31 | 29 |
| 25 | 61 | 56 | 51 |
| 30 | 102 | 92 | 84 |
| 35 | 157 | 139 | 125 |
| 40 | 233 | 204 | 182 |

* Make the inside lane edge radius equal to the turning radius. For all other design speeds, make the lane width 4.5 m.

**T Ramp Design**
**Figure 5-7**

# 6

# Passenger Access

6.01 General
6.02 Passengers
6.03 Bicycles

## 6.01 General

When designing transit stops, consider the safety and comfort of the passengers. Design the whole facility with security in mind by keeping lines of sight as open as possible. Traffic barriers, fencing, illumination, landscaping, seating, windscreens, shelters, enclosed walkways, telephones, and posted schedules are examples of factors that contribute to passenger safety and well-being. See *Design Manual* Chapter 1060, "Transit Benefit Facilities," for guidance that can be applied to transit stops.

## 6.02 Passengers

To encourage use of the passenger access facility for an express transit stop, the obvious course is to provide a route that is the shortest distance to travel from the park and ride lot or local transit stop. Failure to do so might generate the use of undesirable shortcuts. To encourage local use of the passenger access facilities, provide direct access from surrounding neighborhoods.

To access a transit stop in the median or to move about within the facility, grade separations are required for all flyer stop designs except the at-grade crossing flyer stop. Consider stairways, ramps, elevators, and escalators, but provide at least one access for the disabled at every loading platform, as required by the American Disabilities Act of 1990. See *Design Manual* Chapter 1020, "Facilities for Nonmotorized Transportation," for guidance when designing pedestrian grade separations.

In transit stops, at-grade crosswalks are only permitted in the at-grade crossing flyer stop layout described in 4.05(1)(c). Use traffic calming techniques, such as horizontal alignment, textured pavement and crosswalk markings, barrier openings, and other treatments, to channelize pedestrian movements and slow the vehicle movements.

Illuminate transit stop crosswalks and consider providing traffic control signals. (See *Design Manual* Chapter 850, "Traffic Control Signals.") When signalizing, provide advance vehicle detection for pedestrian actuated signals and provide adequate crossing timing for the pedestrian queues that might occur at a transit stop.

Where at-grade crosswalks are not permitted, steps must be taken to minimize unauthorized at-grade crossings. Fencing, taller concrete traffic barrier, enclosed walkways, and ramps are examples to consider.

## 6.03 Bicycles

Bike lanes on nearby streets and separate trails encourage people to bicycle from surrounding neighborhoods. Provide these bicyclists direct access to passenger access facilities.

For bike-bus-bike commuter access to a transit facility, design bicycle access facilities in conjunction with the access for the disabled. (See *Design Manual* Chapter 1020, "Facilities for Nonmotorized Transportation.")

Locate bicycle parking outside of the passenger walkways. See *Design Manual* Chapter 1060, "Transit Benefit Facilities," 1060.03(3)(e), for bicycle parking facilities.

Locations near colleges and universities and locations with good bicycle access, especially near trails, will attract bicyclists. Contact the region Bicycle Coordinator for information on the predicted number of bicycle parking spaces needed and the types of bicycle racks available.

# 7

# Traffic Design Elements

7.01 General
7.02 Traffic Barriers
7.03 Signing
7.04 Lighting
7.05 SC&DI

## 7.01 General

Traffic design elements are critical to the safe and efficient use of HOV direct access facilities. This chapter discusses the elements of traffic design that might be different for HOV direct access facilities.

## 7.02 Traffic Barriers

Separate the main line from the HOV direct access facilities with a traffic barrier. Whenever possible, separate opposing traffic lanes in the facility by using traffic barrier. (See *Design Manual* Chapter 710, "Traffic Barriers.") This is especially important in areas where opposing traffic is changing speeds to or from main line speeds. Concrete barrier is generally preferable on these facilities due to it's low maintenance requirements.

Use gates or moveable barrier sections (such as the Dragnet or BarrierGate systems) at the access points as shown in Figure 4-5 to discourage or prevent use by unauthorized vehicles. Gates and moveable barrier sections can be automated and operated from the transit vehicle. Maintenance and gate operation issues must be addressed when using these devices. Consider alternate access because there is a possibility that these systems might break down. Contact the Olympia Service Center (OSC) Design Office for more information on moveable barrier systems.

The approach ends of traffic barriers must have crashworthy end treatments. In areas where the operating speed is greater than 35 mph, an impact attenuator is required. (See *Design Manual* Chapter 720, "Impact Attenuator Systems.") Consider low maintenance impact attenuators, such as the REACT 350 or QuadGuard LMC, where there is a potential for frequent impacts, such as in gore areas.

When the operating speed is 25 mph or less, and where an at-grade pedestrian crossing transit stop has an opening in a concrete barrier, a sloped-down end as shown in the Standard Plans is acceptable.

When a break in the barrier is required for turning maneuvers, consider the sight distance requirements when determining the location for stopping the barrier. (See *Design Manual* Chapter 650, ”Sight Distance.”)

In areas where headlight glare is a concern, consider taller concrete barrier. Other glare screen options that mount on the top of a barrier tend to be high maintenance items and are discouraged for use on HOV direct access facilities.

Taller barrier might also be desirable in areas where pedestrian access is discouraged such as between opposing flyer stops and between a flyer stop and the main line.

## 7.03 Signing

These guidelines for direct high occupancy vehicle signing follow the general principles in the FHWA’s *Manual on Uniform Traffic Devices* (MUTCD) and WSDOT's *Sign Fabrication Manual*. Should a particular situation occur where the MUTCD, *Sign Fabrication Manual*, and these HOV guidelines are not sufficient, the designer is encouraged to consult the regional Traffic Office or the OSC Traffic Operations Office for guidance.

It is essential that the design and placement of HOV signing clearly indicate whether the signs are intended for motorists in the HOV lane or the general purpose lanes. The purposes of the signs include:

- To enhance safety.
- To convey the message that HOV lanes are restricted to HOVs.
- To provide clear directions for ingress and egress areas.
- To define vehicle occupancy requirements.

Because HOV facilities are not found in many regions, the signing not only considers the commuter but also the occasional user of the facility who might be unfamiliar with the HOV facility and its operation.

### (1) Regional Boundaries

Where HOV corridors overlap regional boundaries, consistency in signing must be maintained to minimize confusion to the motorist. While these guidelines contribute toward a statewide consistency in HOV signing, specific situations will occur where the guidelines are either lacking or not applicable. In those situations, the regions are advised to work with each other and the OSC Traffic Operations Office to ensure consistency in signing. It is also appropriate to consult with outside agencies such as the Washington State Patrol, since enforcement of HOV regulations and HOV signing are related issues.

### (2) Safety

Much of HOV signing relates to enhancing safety for the motorists. Not only are geometrics often minimized due to the lack of right of way, but there are unusual operational characteristics such as the differential speed between the HOV vehicle and the adjacent general purpose traffic. The lack of passing opportunities in the HOV lane and the necessity for frequent merging and weaving actions require designers to use messages that are clear and concise, and use symbols wherever possible.

Because left-side off-connections are unusual, advance signing warning that an exit is on the left becomes a consideration.

For T ramps, provide traffic control at the T to assign priority to one of the conflicting left-turn movements and to avert wrong way movements.

### (3) Diamond Symbols

WSDOT uses the diamond symbol to designate all HOV facilities. For all signs, whether regulatory, guide, or warning, the symbol is always white on a black background to convey the restrictive nature of the HOV lane and to make the signs more uniformly recognizable. The use of the symbol with all HOV signs also informs drivers, whether they are in the general purpose lanes or HOV lane, that the message is only intended for HOVs.

### (4) Selection and Location

The signing details, “Typical Direct HOV Access Signing” and “Typical Flyer Stop Signing” (Figures 7-2 through 3b), provide guidance for the HOV geometric configurations that

might be used within the right of way. In general, signing for other types of HOV facilities (such as those used for reversible-flow, and HOV direct access between freeways and temporary HOV lanes used during construction) is designed on a case-by-case basis requiring consultation with the appropriate OSC and region traffic personnel. In general, the design of signing for HOV direct access between freeways will include HOV guide signs, both advance and action, in addition to the normal regulatory signs. Signing for reversible-flow HOV facilities is done on a case-by-case basis.

### (5) Regulatory Signs

Regulatory signs for HOV facilities follow the normal regulatory signing principles; black legend with a white reflective background on a rectangular panel. Keep in mind that messages conveyed by the HOV signs (such as signs concerning violations and those indicating the beginning of an HOV lane downstream) are not necessarily intended only for the HOV vehicle. Therefore, it might be prudent to place additional signs on the right side of the freeway where this conforms to sound engineering practice and can be done economically.

### (6) Guide Signs

Guide signs for the HOV facilities are generally used at intermediate on and off locations to inform HOV motorists of upcoming freeway exits and the appropriate location to exit the HOV lane. For HOV direct access to and from arterials, guide signs are used in a fashion similar to normal arterial interchange signing practice. The guide signs have a black nonreflective legend on a white reflective background. The exception is the diamond, where the white reflective symbol is on a black nonreflective background. For all HOV related guide signs, the diamond is placed in the upper left-hand corner of the sign.

### (7) Visibility

The reflective sheeting used for HOV signs is required to meet the reflective sheeting requirements in *Traffic Manual* Chapter 2, “Signs.” Illumination for overhead signs is required to follow the current policy for overhead signs in *Design Manual* Chapter 820, “Signing.”

## 7.04 Lighting

Illumination of HOV direct access facilities is required for ramps, loading platforms at transit stops, major parking lots, and walkways as defined in *Design Manual* Chapter 840, "Illumination." Additional direction and design considerations are contained in *Traffic Manual* Chapter 4, "Signals and Illumination." The approval of the State Traffic Engineer is required for proposals that provide less than or more than the amount of lighting stated in these manuals.

Metric versions of the required design light levels are expressed in LUX. See Figure 7-1

## 7.05 SC&DI

Surveillance, control, and driver information (SC&DI) systems are used to collect traffic data, maintain freeway flow, and disseminate traveler information. Transit information systems for passengers and transit facility surveillance are not normally a part of WSDOT's SC&DI system, but implementation of these components can be considered for some locations.

Design of HOV direct access facilities, like all HOV facilities, should fully utilize available SC&DI elements. Need for SC&DI elements varies depending on project features, such as facility design and operation, and whether the site has existing SC&DI components.

SC&DI elements that might be applicable to HOV direct access facilities include: closed circuit television surveillance, ramp metering, data collection, exit queue detection and override, dynamic signing, transit signal priority, automatic vehicle identification and location, and gate control.

Guidance on the development of SC&DI elements is found in *Design Manual* Chapter 1050 and the Northwest Region's *SC&DI Design Guide*. Include the region Traffic Office, transit operator, and affected local agency in the coordination for design and implementation of SC&DI elements.

| Highway Applications | | | | |
|---|---|---|---|---|
| | Area Classification | | | |
| **Highway Class** | **Commercial** | **Intermediate** | **Residential** | **Rural** |
| Full Access Control - Divided | 6.5* | 6.5* | 6.5* | 6.5* |
| Arterials | 17.2 | 12.9 | 8.6* | 6.5* |
| Other | 10.8 | 8.6* | 6.5* | 6.5* |
| Construction Lanes and Detours | 10.8 | 10.8 | 10.8 | 10.8 |
| **Nonhighway Applications** | | | | |
| | **Parking Areas** | **Bus Loading Areas** | **Walkways** | **Weight Scales** |
| Park & Ride Lots | 8.6 | 21.5 | 8.6 | Not Applicable |
| Flyer Stops | Not Applicable | 21.5 | 8.6 | Not Applicable |
| Ferry Terminals | 8.6 | 21.5 | 8.6 | Not Applicable |
| Rest Areas | 8.6 | Not Applicable | Security Level | Not Applicable |
| Pool-It Lots | 8.6 | Not Applicable | Not Applicable | Not Applicable |
| Weigh Stations | ** | Not Applicable | Not Applicable | 2 Luminaires |

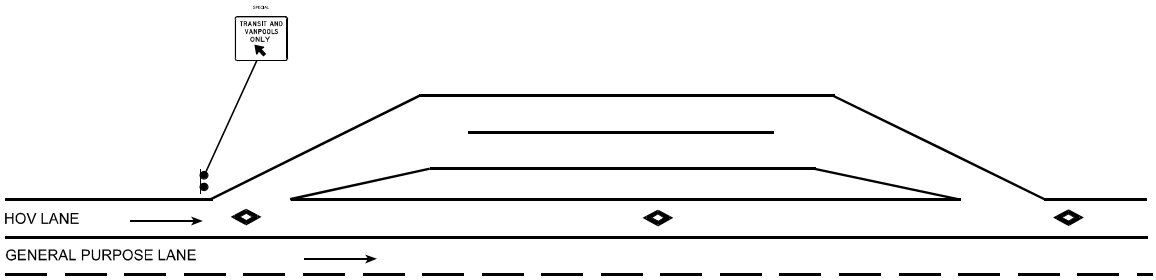
Notes:

* Increase light level by 50% at intersections where more than one light standard is installed

** Provide light standards in inspection areas

LUX x 0.0929 = fc

**Average Maintained Horizontal Illumination Levels (LUX)**
**Figure 7-1**

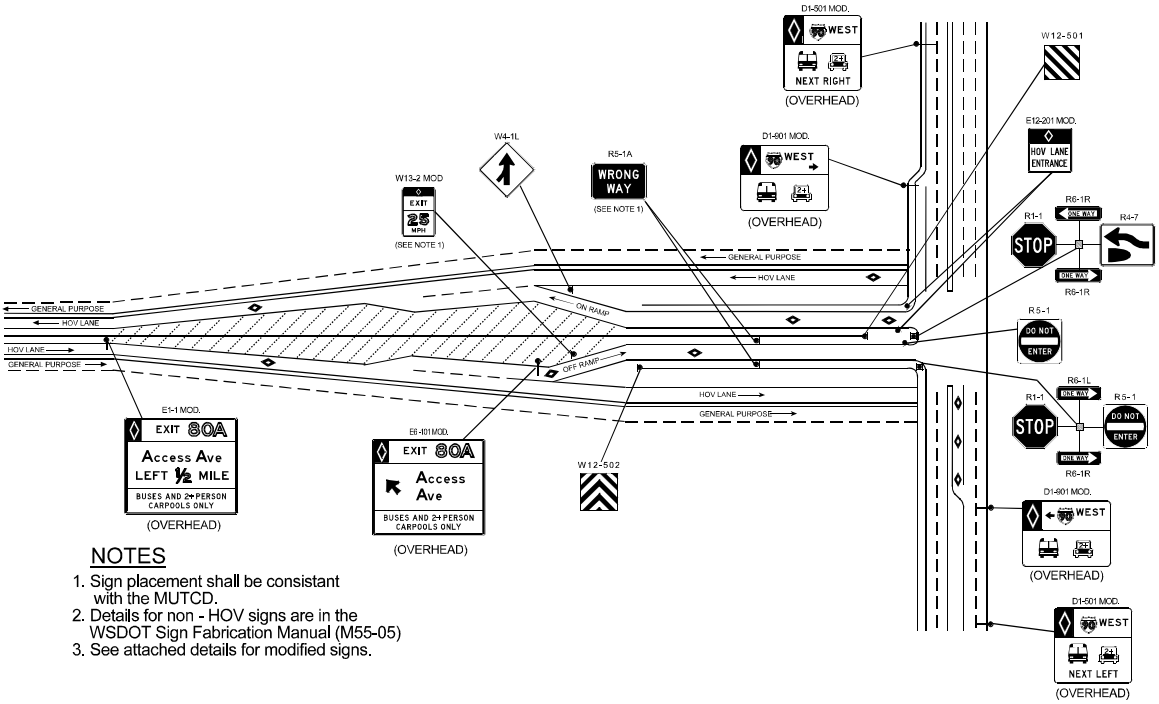


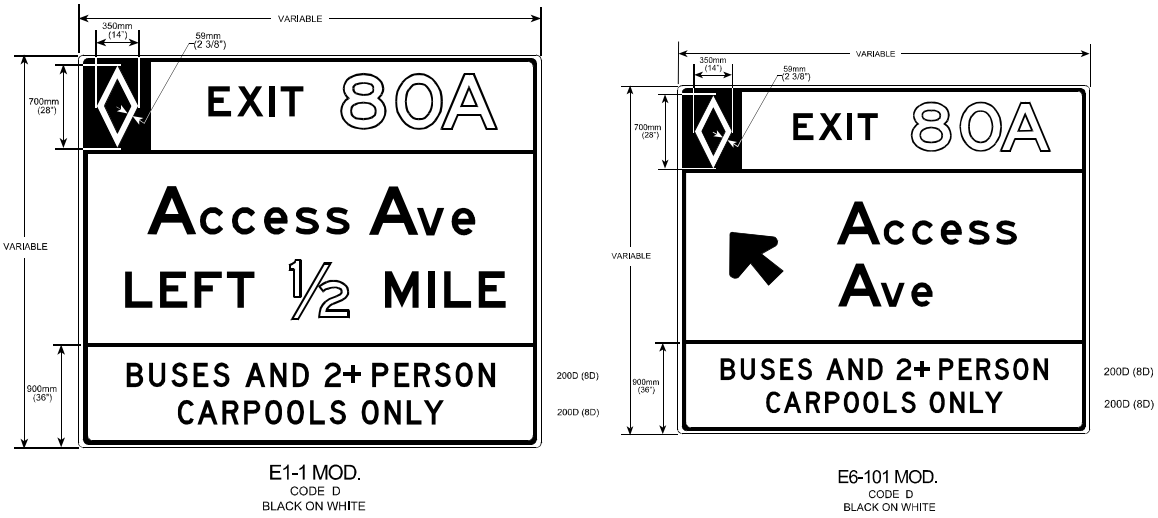

**Typical Signing for Flyer Stop**

SPECIAL
BLACK ON WHITE

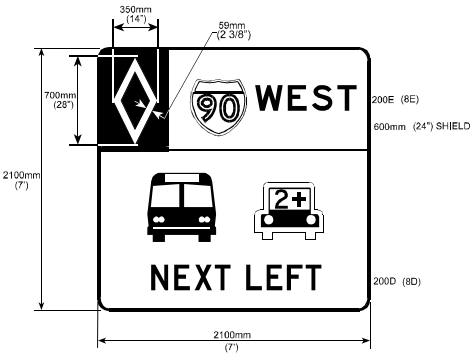
**Special Flyer Stop Sign**

**Flyer Stop Signing**
**Figure 7-2**

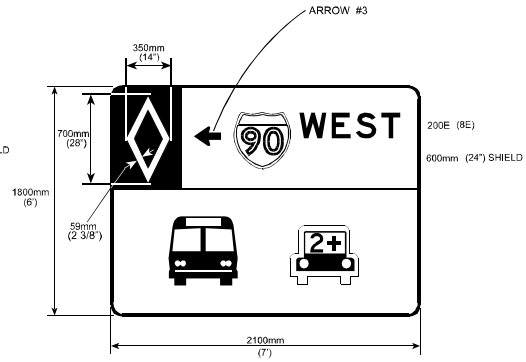


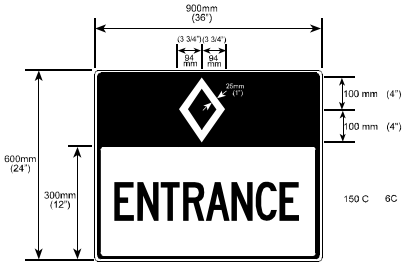

**HOV Direct Access Signing**
**Figure 7-3a**



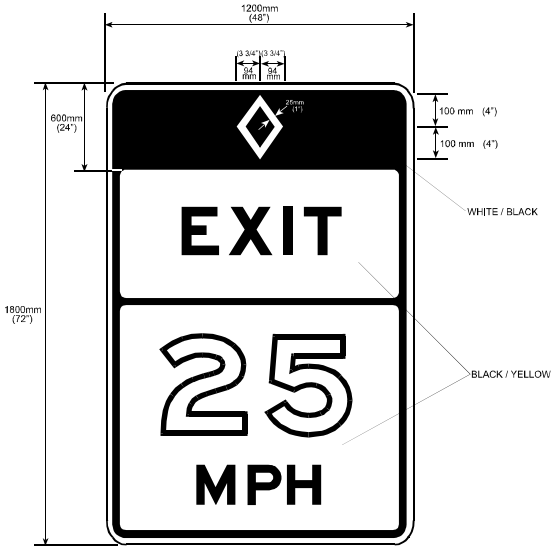

D1-501 MOD.
BLACK ON WHITE




D1-901 MOD.
BLACK ON WHITE




E12-201 MOD.
BLACK ON WHITE




**W13-2 MOD**

**HOV Direct Access Signing (continued)**
**Figure 7-3b**

# 8

# Appendices

8.01 Sources for Design Values
8.02 Conversion Symbols
8.03 Units of Measurement
8.04 Conversion Factors
8.05 The Construction Trades
8.06 Pavement Conversion Factors

## 8.01 Sources for Design Values

See Chapter 2, "References," for detailed titles and sources for the following publications.

The AASHTO Green Book is the source of most of the information in the *HOV Direct Access Design Guide*. The following are the exceptions.

### (1) Gap Acceptance Distances

The gap acceptance distances ($L_g$) are based on the advanced warning sign placement distances from the MUTCD. This is the distance traveled in ten seconds at the posted speed less 125 ft (38 m).

$$L_g = \left(10kV_p\right) - 38 \qquad \text{Equation (1)}$$

Where: Lg = Gap acceptance distance (m)
Vp = Posted speed (mph)
k = The conversion from mph to m/sec (mph * 0.45 = m/sec)

The values were recalculated with Equation (1), to avoid rounding errors, and rounded up to the next 5 m.

### (2) Deceleration Lengths

Deceleration lengths were calculated for a bus passenger comfort level of 2.5 mph per second based on Table 15 of NCHRP Report 155, "Bus Use of Highways," and a change from the average running speed of the highway to the average running speed of the ramp. Figure 8-1 shows the relationship between the design speed and the average running speed used.

The deceleration lengths were calculated using Equation (2) and rounded up to the next 5 m.

$$S = \frac{(V_r k)^2 - (Vk)^2}{2a}$$ Equation (2)

Where: S = Deceleration length (m)
$V_r$ = Average running speed of the highway, see Figure 8-1 (mph)
V = Average running speed of the ramp, see Figure 8-1 (mph)
a = Deceleration rate (1.12 m/sec$^2$)
k = The conversion from mph to m/sec (1 mph = 0.45 m/sec)

This produced lengths that are from 155 m longer to 20 m shorter than obtained from the converted AASHTO English values. The lengths that were shorter were increased to equal the AASHTO lengths.

| Design Speed | Running Speed | Speed at Merging |
|---|---|---|
| 15 | 14 | 9 |
| 20 | 18 | 13 |
| 25 | 22 | 17 |
| 30 | 27 | 22 |
| 35 | 31 | 26 |
| 40 | 36 | 31 |
| 45 | 40 | 35 |
| 50 | 44 | 39 |
| 55 | 48 | 43 |
| 60 | 52 | 47 |
| 65 | 55 | 50 |
| 70 | 58 | 53 |
| 80 | 64 | 59 |

**Relation of Design, Running, and Merging Speeds**
**Figure 8-1**

### (3) Acceleration Lengths

Acceleration lengths were calculated based on Figure 45 "Speed versus distance comparison of 40-ft and 60-ft articulated buses" in the WA-RD 396.1 Final Technical Report. (See Figure 8-2.)

The distances (m) required for a 60' bus to reach a given speed (km/h) from a stop were picked from the chart. Assuming that the distance required to change from one speed to another is the same regardless of whether starting at the first speed or accelerating from a stop, distances needed to accelerate between speeds were calculated. Using Equation (3), acceleration rates (m/sec) were calculated for the speed changes. The acceleration rates were interpolated to the required speeds in mph and the required acceleration distances were calculated using Equation (4) and rounded up to the next 5 m.

$$a = \frac{V^2 - (V_0 j)^2}{2S} \qquad \text{Equation (3)}$$

Where: a = Acceleration rate (m/sec$^2$)
V = Speed reached (km/h)
$V_0$ = Starting speed (km/h)
S = Distance (m)
j = The conversion from km/h to m/sec (1 km/h = 0.278 m/sec)

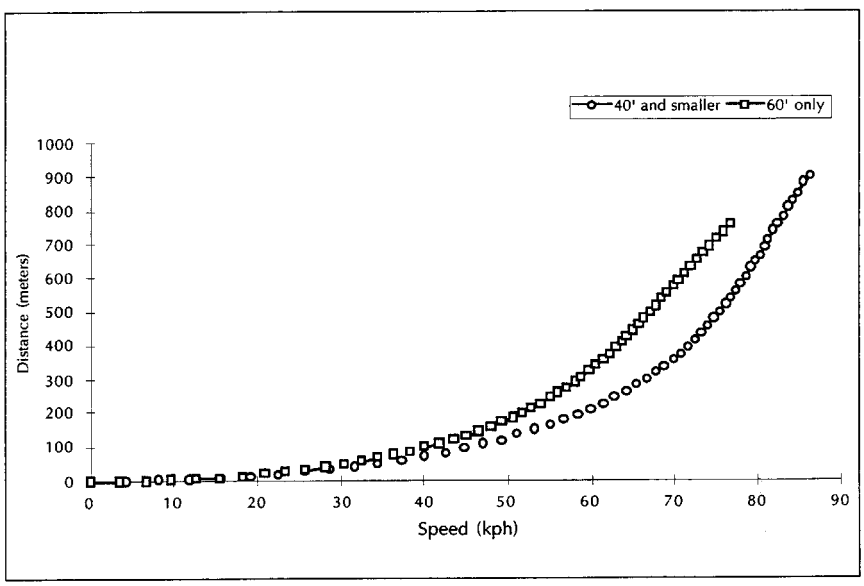



**Figure 45.** *Speed versus distance comparison of 40-ft and 60-ft articulated buses*

**Figure 8-2**

$$S = \frac{(V_m k)^2 - (Vk)^2}{2a}$$ Equation (4)

Where: S = Deceleration length (m)
$V_m$ = Speed of merging with the highway, see Figure 8-1 (mph)
V = Average running speed of the ramp, see Figure 8-1 (mph)
a = Acceleration rate (1.12 m/sec$^2$)
k = The conversion from mph to m/sec (1 mph = 0.45 m/sec)

## 8.02 Conversion Symbols

The prefixes and symbols listed below are commonly used to form names and symbols of the decimal multiples and submultiples of the units.

| Multiplication Factor | Prefix | Symbol |
|---|---|---|
| 1 000 000 000 = $10^9$ | giga | G |
| 1 000 000 = $10^6$ | mega | M |
| 1 000 = $10^3$ | kilo | k |
| 100 = $10^2$ | hecto | h |
| 1 = 1 | | |
| 0.01 = $10^{-2}$ | centi | c |
| 0.001 = $10^{-3}$ | milli | m |
| 0.000 001 = $10^{-6}$ | micro | µ |
| 0.000 000 001 = $10^{-9}$ | nano | n |

## 8.03 Units of Measurement

| Units of Measurement as Used in the Standard Item Table | Metric Equivalent |
|---|---|
| acre | hectare (ha) |
| cubic foot | cubic meter ($m^3$) |
| cubic yard | cubic meter ($m^3$) |
| gallon; m gallon | liter (L); cubic meter ($m^3$) |
| hundred | hundred (for traffic buttons) |
| hundred weight | kilogram (kg) |
| linear foot | meter (m) |
| mboard feet | cubic meter ($m^3$) |
| mile | kilometer (km) |
| nautical mile | nautical mile |
| pound | kilogram (kg) for mass |
| pound | newton (N) for force |
| square foot | square meter ($m^2$) |
| square yard | square meter ($m^2$) |
| ton | tonne (t) |

| Units of Measurement Used in Special Provisions and General Special Provisions | | Metric Equivalent |
|---|---|---|
| gage; gauge | metal thickness | gage (mm) |
| Fahrenheit | temperature | kelvin (k) |
| Fahrenheit | temperature | degree Celsius (°C) |
| fathom | water depth | meter (m) |
| foot/lbs | torque | newton·meter (N·m) |
| lbs/sq in | pressure | kilopascal (kPa) |
| lbs/sq in | pressure | megapascal (MPa) |
| lbs/sq ft | pressure | kilopascal (kPa) |
| lbs/sq yd | pressure | kilopascal (kPa) |
| inch | linear | millimeter (mm) |
| kips; ksi | tension | kilopascal (kPa) |
| kips; ksi | tension | megapascal (MPa) |
| lbs/acre | erosion control | kilograms/hectare |
| lbs/ cu ft | density | kilogram per cubic meter (kg/m$^3$) |
| mil | thickness | micrometer (um) |
| ft-lbs/sec | horse power | watt (W) |

| Units of Measurement Used on Contract Plans | Metric Equivalent |
|---|---|
| degrees/bearings | No change for surveying |
| stationing | 1,000 meters = 1 station |
| mileposts | No change for mileposts |
| elevations | meter (m) |

| Units of Measurement Used in Commercial Standards | Metric Equivalent |
|---|---|
| gals/hr or min (pumps) | liter per second (L/s) |
| 500 gallon tanks | cubic meter (m$^3$) but it could also possibly be in liter (L) |
| 55 gallon drums | cubic meter (m$^3$) or liter (L) for liquid |
| 94 lbs/sack (cement) | kilogram (kg) |
| diameter of reinforcing steel | millimeter (mm) |
| lbs/ft of reinforcing steel | kilogram per meter (kg/m) |
| bushel | cubic meter (m$^3$) |

## 8.04 Conversion Factors

| Quantity | From English Units | To Metric Units | Multiply by* |
|---|---|---|---|
| length | mile | km | 1.609344 |
| | yard | m | 0.9144** |
| | foot | m | 0.3048** |
| | inch | mm | 25.40** |
| area | square mile | $km^2$ | 2.590 |
| | acre | $m^2$ | 4047 |
| | acre | hectare | 0.4047 |
| | square yard | $m^2$ | 0.8361 |
| | square foot | $m^2$ | 0.092 90 |
| | square inch | $mm^2$ | 645.2 |
| volume | acre foot | $m^3$ | 1 233 |
| | cubic yard | $m^3$ | 0.7646 |
| | cubic foot | $m^3$ | 0.028 32 |
| | cubic foot | L (1000 $cm^3$) | 28.32 |
| | 100 board feet | $m^3$ | 0.2360 |
| | gallon | L (1000 $cm^3$) | 3.785 |
| mass | lb. | kg | 0.4536 |
| | kip (1000 lb) | metric ton (1000 kg) | 0.4536 |
| mass/unit length | plf | kg/m | 1.488 |
| mass/unit area | psf | $kg/m^2$ | 4.882 |
| mass density | pcf | $kg/m^3$ | 16.02 |
| force | lb | N | 4.448 |
| | kip | kN | 4.448 |
| force/unit length | plf | N/m | 14.59 |
| | klf | kN/m | 14.59 |
| pressure, stress modules elasticity | psf | Pa | 47.88 |
| | ksf | kPa | 47.88 |
| | psi | kPa | 6.895 |
| | ksi | MPa | 6.895 |
| bending moment | ft-lb | N·m | 1.356 |
| torque, moment of force | ft-kip | kN·m | 1.356 |
| moment of mass | lb-ft | kg·m | 0.1383 |
| moment of inertia | $lb\text{-}ft^2$ | $kg{\cdot}m^2$ | 0.042 14 |
| second moment of area | $in^4$ | $mm^4$ | 416 231 |
| section modulus | $in^3$ | $mm^3$ | 16 387 |

| | | | |
|---|---|---|---|
| power | ton (refrig) | kW | 3.517 |
| | Btu/s | kW | 1.055 |
| | hp (electric) | W | 7467 |
| | Btu/h | W | 0.293 |
| volume rate of flow | $ft^3/s$ | $m^3/s$ | 0.028 32 |
| | cfm | $m^3/s$ | 0.000 471 9 |
| | cfm | L/s | 0.4719 |
| velocity, speed | ft/s | m/s | 0.3048** |
| acceleration | $f/s^2$ | $m/s^2$ | 0.3048 |
| momentum | lb-ft/sec | kg·m/s | 0.1383 |
| angular momentum | $lb\text{-}ft^2/s$ | $kg{\cdot}m^2/s$ | 0.042 14 |
| plane angle | degree | rad | 0.017 45 |
| | | mrad | 17.45 |

* 4 significant digits

**denotes exact conversion

## 8.05 The Construction Trades

These are the metric units that will be used by the construction trades. The term "length" includes all linear measurements--length, width, height, thickness, diameter, and circumference.

| Quantity | Unit | Symbol | |
|---|---|---|---|
| Surveying | length | kilometer, meter | km, m |
| | area | square kilometer | $km^2$ |
| | area | hectare (10,000 $m^2$) | ha |
| | area | square meter | $m^2$ |
| | plane angle | degree (nonmetric) | ° |
| | plane angle | minute (nonmetric) | ′ |
| | plane angle | second (nonmetric) | ″ |
| Excavating | length | meter, millimeter | m, mm |
| | volume | cubic meter | $m^3$ |
| Trucking | distance | kilometer | km |
| | volume | cubic meter | $m^3$ |
| | mass | metric ton (1000 kg) | t |
| Paving | length | meter, millimeter | m, mm |
| | area | square meter | $m^2$ |
| Concrete | length | meter, millimeter | m, mm |
| | area | square meter | $m^2$ |
| | volume | cubic meter | $m^3$ |
| | temperature | degree Celsius | °C |
| | water capacity | liter (1000 cm) | L |
| | mass (weight) | kilogram, gram | kg, g |
| | cross-sectional area | square millimeter | $mm^2$ |

## 8.06 Pavement Conversion Factors

### Metric Conversion--Pavements

| Roadway ft | Dimensions ft | Dimensions m | Bridge Height ft | Bridge Height m | PCCP Thickness (inches) | PCCP Thickness (mm) | Resilient Modulus psi | Resilient Modulus MPa |
|---|---|---|---|---|---|---|---|---|
| Lane | 12 | 3.6 | 14.5 | 4.4 | 9 | 225 | 3,000 | 21 |
| Shoulder | 4 | 1.2 | 16.0 | 4.9 | 10 | 250 | 4,000 | 28 |
| | 10 | 3.0 | | | 11 | 275 | 5,000 | 34 |
| | | | | | 12 | 300 | 10,000 | 69 |
| | | | | | | | 12,000 | 83 |
| | | | | | | | 15,000 | 103 |
| | | | | | | | 20,000 | 138 |

### Typical Density Values

| | pcf | $kg/m^2$ | Axle Loads lbs | Axle Loads kN | Tire Loads (per tire width) lbs/inch | Tire Loads (per tire width) kg/mm |
|---|---|---|---|---|---|---|
| PCCP | 150 | 2403 | 18,000 | 80 | 500 | 9 |
| ACP | 137/0.10 depth | 2439 | | | | |

### Typical Quantities

**Asphalt Concrete Paving Quantities**

| | | Depth of Pavement | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ft ⇨ | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 | 0.65 | 0.70 | 0.75 |
| | mm ⇨ | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 | 95 | 210 | 225 |
| ⇩ Width of pavement | | | | | | | | | | | | | | | |
| ft | mm | Metric tons per kilometer | | | | | | | | | | | | | |
| 4 | 1.2 | 88 | 132 | 176 | 219 | 263 | 307 | 351 | 395 | 439 | 483 | 527 | 571 | 614 | 658 |
| 6 | 1.8 | 132 | 198 | 263 | 329 | 395 | 461 | 527 | 593 | 658 | 724 | 790 | 856 | 922 | 988 |
| 8 | 2.4 | 176 | 263 | 351 | 439 | 527 | 614 | 702 | 790 | 878 | 966 | 1,053 | 1,141 | 1,229 | 1,317 |
| 10 | 3.0 | 219 | 329 | 439 | 549 | 658 | 768 | 878 | 988 | 1,097 | 1,207 | 1,317 | 1,427 | 1,536 | 1,646 |
| 11 | 3.3 | 241 | 362 | 483 | 604 | 724 | 845 | 966 | 1,086 | 1,207 | 1,328 | 1,448 | 1,569 | 1,690 | 1,811 |
| 12 | 3.6 | 263 | 395 | 527 | 658 | 790 | 922 | 1,053 | 1,185 | 1,317 | 1,448 | 1,580 | 1,712 | 1,843 | 1,975 |
| 22 | 6.6 | 483 | 724 | 966 | 1,207 | 1,448 | 1,690 | 1,931 | 2,173 | 2,414 | 2,655 | 2,897 | 3,138 | 3,380 | 3,621 |
| 24 | 7.2 | 527 | 790 | 1,053 | 1,317 | 1,580 | 1,843 | 2,107 | 2,370 | 2,634 | 2,897 | 3,160 | 3,424 | 3,687 | 3,950 |

Based on 2439 $kg/m^3$ 30 mm compacted depth = 73.17 $kg/m^2$

**Note**: Additional estimating tables are shown in *Design Manual* Chapter 520, "Design of Pavement Structures."

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