Transportation System Engineering 2 , 10601461

Chapter 4
Intersection Design

AN-NAJAH NATIONAL UNIVERSITY
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Outline: Chapter 4

4.1 Types and Design of At Grade Intersections

4.2 Geometric Design Principles of At-Grade Intersections

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Intersection Design

- An intersection is an area, shared by two or more roads, which has the **main function of providing for the change of route directions**
- Intersections tend to have a high potential for crashes
  - Drivers have to make decisions concerning which of the alternative routes they wish to take
- The overall traffic flow on any highway depends on the performance of the intersections
  - since intersections usually operate at lower capacities

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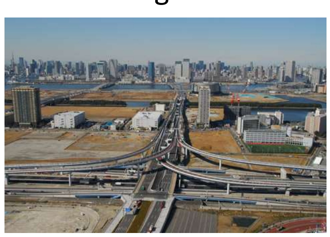
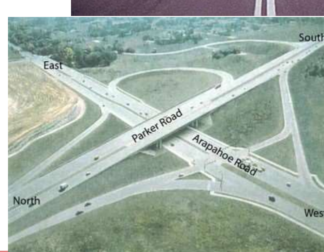
Intersection Design

- Intersections are classified into:
  1. **Grade-separated without ramps**: traffic cross at different levels (vertical distances) without interruption
  2. **Grade-separated with ramps** (commonly known as interchanges





The potential for crashes is reduced because many potential conflicts are eliminated

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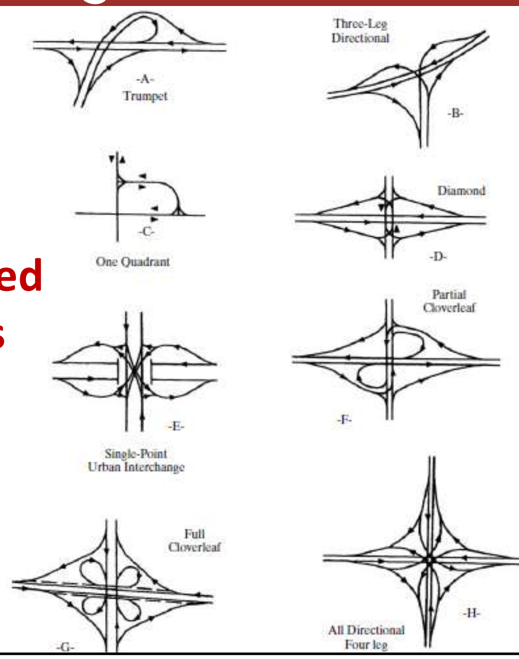
Intersection Design

Grade-separated intersections



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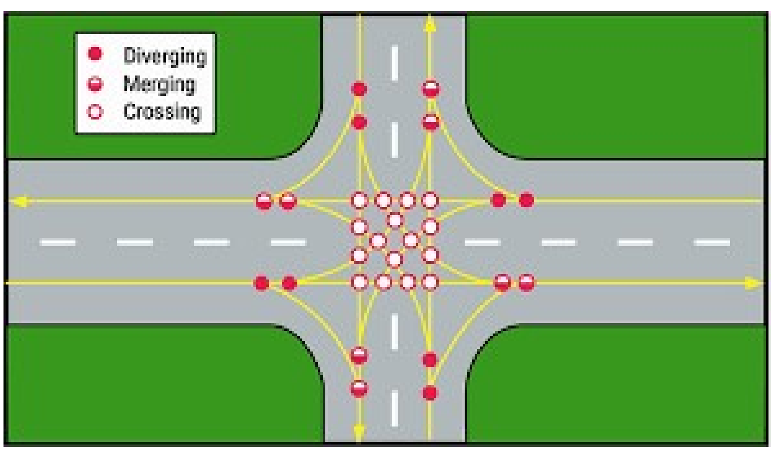
Traffic Flow Theory

- Intersections are classified into:
  3. **At-grade intersections**: there exist conflicts between intersecting streams of traffic



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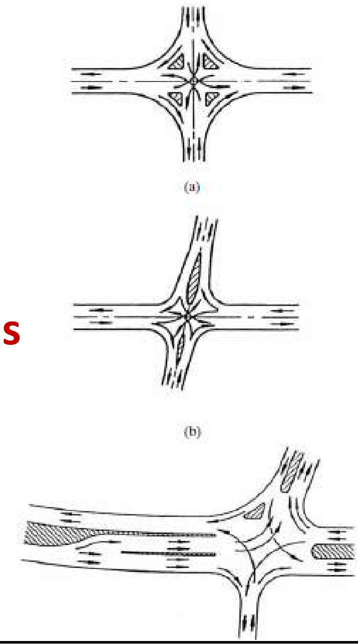
Intersection Design

At-grade intersections



4.1 Types and Design of At Grade Intersections

Types of At-Grade Intersections

① **T or three-leg** intersections which consist of three approaches;

② **Four-leg** or cross intersections, which consist of four approaches

③ **Multi-leg** intersections, which consist of five or more approaches

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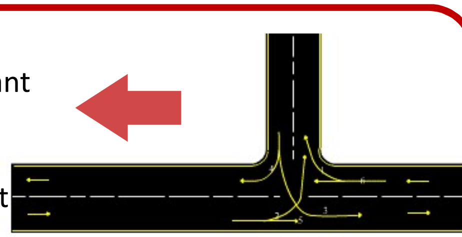
Types of At-Grade Intersections

① **T or three-leg** intersections:

- T intersections ranging from the simplest to a channelized one with divisional islands and turning roadways
- **Channelization** involves the provision of facilities such as pavement markings and traffic islands to regulate and direct conflicting traffic streams into specific travel paths

- Used when
  - Minor roads intersect important highways with an intersection angle less than 30 degrees.
  - In rural two-lane highways that carry light traffic.



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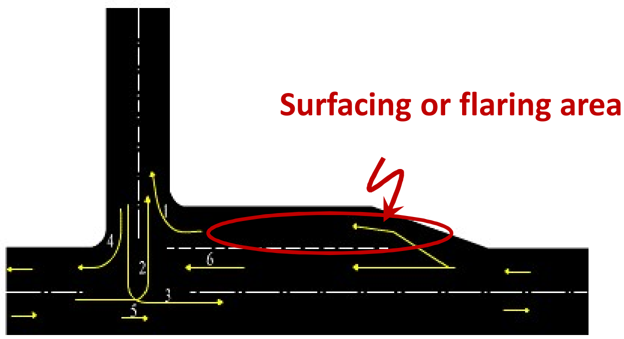
Types of At-Grade Intersections

① **T or three-leg** intersections:

- At locations with higher speeds and turning volumes
  - increase the potential of rear-end collisions between through vehicles and turning vehicles

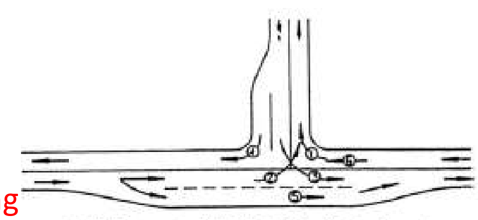


Types of At-Grade Intersections

① **T or three-leg** intersections:

- Where left-turn volume from a through road onto a minor road is sufficiently high
  - but does not require a separate left-turn lane

- An auxiliary lane is provided to allow through vehicles to maneuver around left-turning vehicles

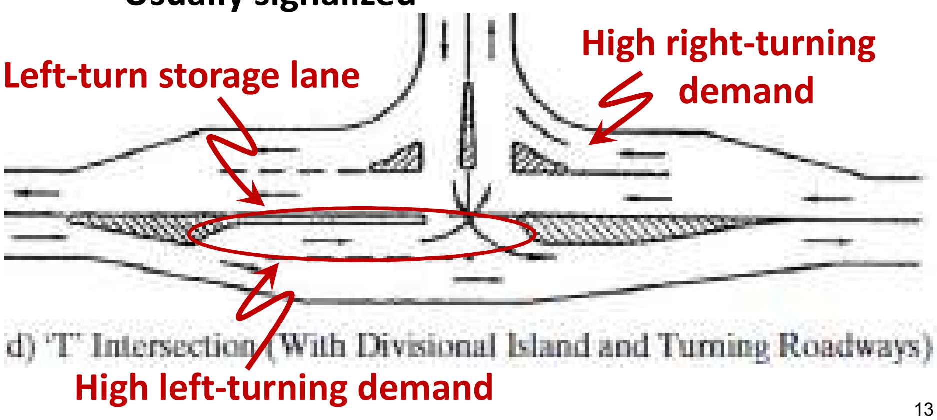


(c) 'T' Intersection (With Right-Hand Passing Lane)

Types of At-Grade Intersections

① **T or three-leg** intersections:

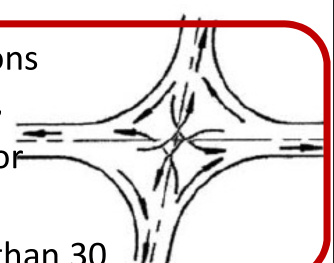
- Two-lane through road has been converted into a divided highway
- **Usually signalized**



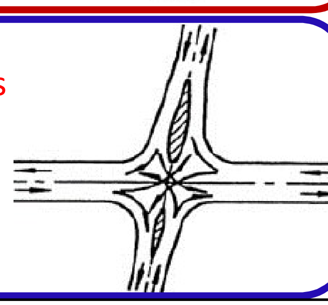
Types of At-Grade Intersections

② **Four-leg** intersections:

- Un-channelized, mainly at locations where minor or local roads cross,
- Where minor road crosses a major highway.
- Intersection angle is not greater than 30



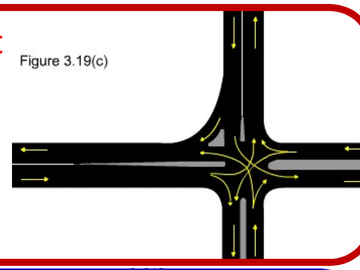
- When right-turning movements are frequent
- Common in suburban areas where pedestrians are present



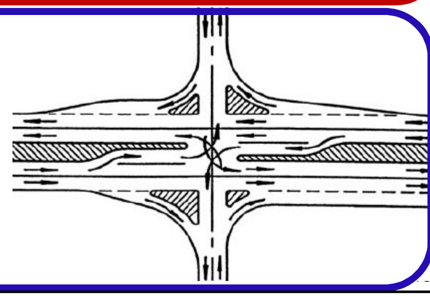
Types of At-Grade Intersections

② **Four-leg** intersections:

- At two-lane highways that are not minor crossroads
- Carries moderate volumes at high speeds or operates near capacity



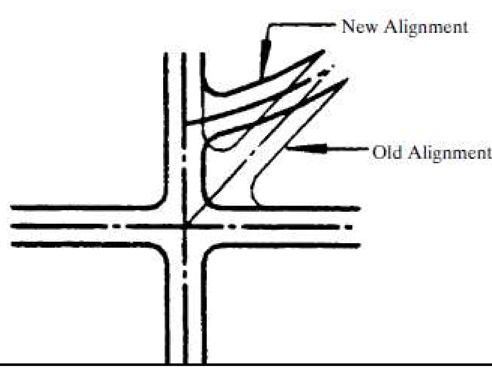
- At four-lane approaches carrying high through and turning volumes
- **Usually signalized**



Types of At-Grade Intersections

③ **Multi-leg** intersections:

- Whenever possible, this type of intersection should be avoided
- **One or more of the legs are realigned**, to remove some of the conflicting movements increase safety and operation



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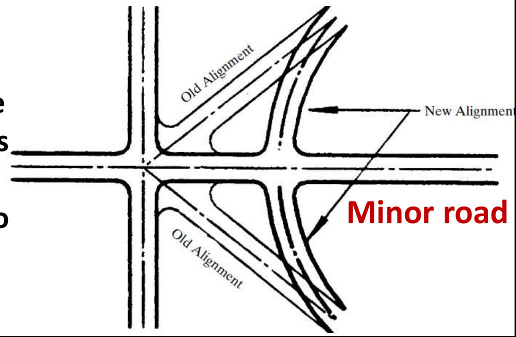
Types of At-Grade Intersections

③ **Multi-leg** intersections:

– **Intersection re-alignement**: Two important factors:
1. Diagonal road are realigned to the minor road
2. The distance between the intersections should be such that they can operate independently

If the right-to-left direction is the major road, each diagonal road is realigned to the road in the top-to-bottom direction, forming two additional T intersections



Types of At-Grade Intersections

④ **Traffic Circles**: It is a circular intersection that provides a circular traffic pattern with significant reduction in the crossing conflict points

– Three Types of traffic circles:

a. Rotaries

b. Neighborhood traffic circles

c. Roundabouts

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Types of At-Grade Intersections

a. Rotaries:

- Large diameters that are usually greater than 300ft
  - Allowing speeds exceeding 30 mi/h, with a minimum horizontal deflection of the path

b. Neighborhood traffic circles:

- Their diameters are much smaller than rotaries and therefore allow much lower speeds.
  - At intersection of local streets as a means of traffic calming and/or as an aesthetic device
  - Using pavement markings, not raised islands
  - Stop control or no control
  - Parking might be allowed within circulatory roadway

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Types of At-Grade Intersections

c. Roundabouts: They have specific defining characteristics that separate them from other circular intersections

- These characteristics include:
  - Yield control at each approach
  - Separation of conflicting traffic movements by pavement markings or raised islands
  - Geometric characteristics of the central island that typically allow travel speeds of less than 30 mi/h
  - Parking not usually allowed within the circulating roadway

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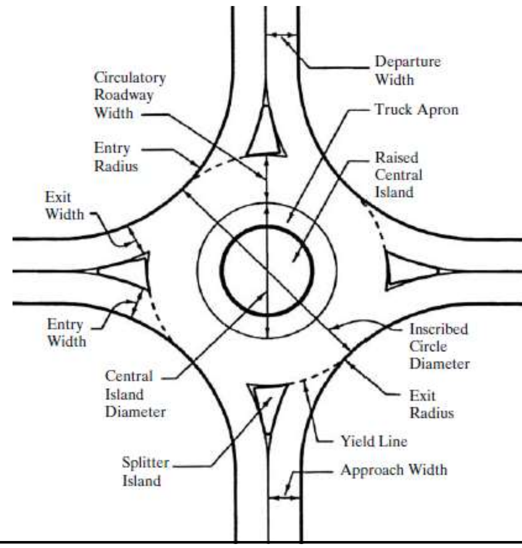
Types of At-Grade Intersections

c. Roundabouts:

Geometric elements of a single-lane modern roundabout



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Types of At-Grade Intersections

c. **Roundabouts:** Roundabouts can be further categorized into six classes based on the size and environment in which they are located.

- Mini roundabouts
- Urban compact roundabouts
- Urban single-lane roundabouts
- Urban double-lane roundabouts
- Rural single-lane roundabouts
- Rural double-lane roundabouts

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Types of At-Grade Intersections

c. **Roundabouts:**

Table 7.1 Characteristics of Roundabout Categories

Design Element	*Mini-Roundabout*	*Urban Compact*	*Urban Single-Lane*	*Urban Double-Lane*	*Rural Single-Lane*	*Rural Double-Lane*
Recommended maximum entry design speed	25 km/h (15 mi/h)	25 km/h (15 mi/h)	35 km/h (20 mi/h)	40 km/h (25 mi/h)	40 km/h (25 mi/h)	50 km/h (30 mi/h)
Maximum number of entering lanes per approach	1	1	1	2	1	2
Typical inscribed circle diameter[1]	13 to 25 m (45 ft to 80 ft)	25 to 30 m (80 to 100 ft)	30 to 40 m (100 to 130 ft)	45 to 55 m (150 to 180 ft)	35 to 40 m (115 to 130 ft)	55 to 60 m (180 to 200 ft)
Splitter island treatment	Raised if possible, crosswalk cut if raised	Raised, with crosswalk cut	Raised, with crosswalk cut	Raised, with crosswalk cut	Raised and extended, with crosswalk cut	Raised and extended, with crosswalk cut
Typical daily service volumes on four-leg roundabout (veh/day)	10,000	15,000	20,000	Refer to the source	20,000	Refer to the source

[1]Assumes 90° entries and no more than four legs.

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4.2 Geometric Design Principles of At-Grade Intersections

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Design Principles of At-Grade Intersections

- The fundamental objective is to minimize the severity of potential conflicts among different streams of traffic and between pedestrians and turning vehicles.
  - At the same time, it is necessary to provide for the smooth flow of traffic across the intersection.

The design should incorporate the operating characteristics of both vehicles and pedestrians.

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Design Principles of At-Grade Intersections

- The corner radius of an intersection pavement:
  - It should not be less than either the turning radius of the design vehicle or the radius required for design velocity of the turning roadway under consideration.
  - It should also ensure adequate pavement widths of turning roadways and approach sight distances

At-grade intersections should not be located at or just beyond sharp crest vertical curves or at sharp horizontal curves

Approaches of the intersection should preferably intersect at angles less than 30° from the normal

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Design Principles of At-Grade Intersections

1. **Alignment of At-Grade Intersections**
2. **Profile of At-Grade Intersections**
3. **Curves at At-Grade Intersections**
4. **Channelization of At-Grade Intersections**
5. **Minimum Pavement Widths of Turning Roadways**
6. **Sight Distance at Intersections**

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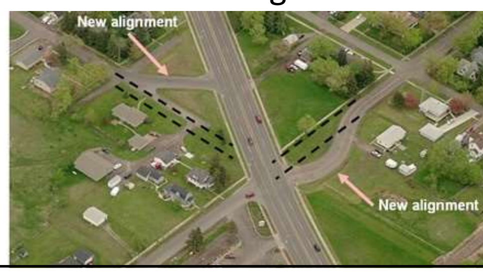
① Alignment of At-Grade Intersections

- The best alignment is when the intersecting roads meet at right or nearly right angles
  - It is superior to acute-angle alignments
- At right or nearly right angles intersections:
  - Much less road area is required for turning
  - Visibility limitations (particularly for trucks) are not as serious as those at acute-angle intersections



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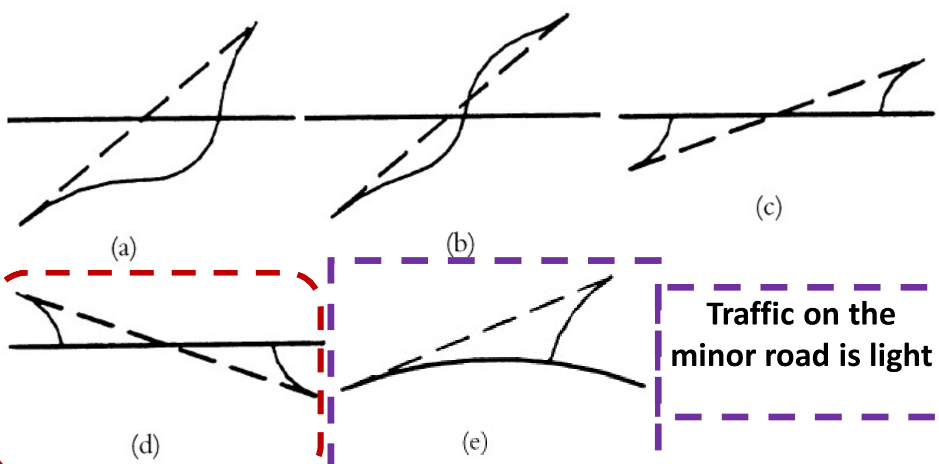
① Alignment of At-Grade Intersections



Traffic on the minor road is light

It is preferable because the minor-road vehicle is required to make a right turn rather than a left turn from the major road to reenter the minor road

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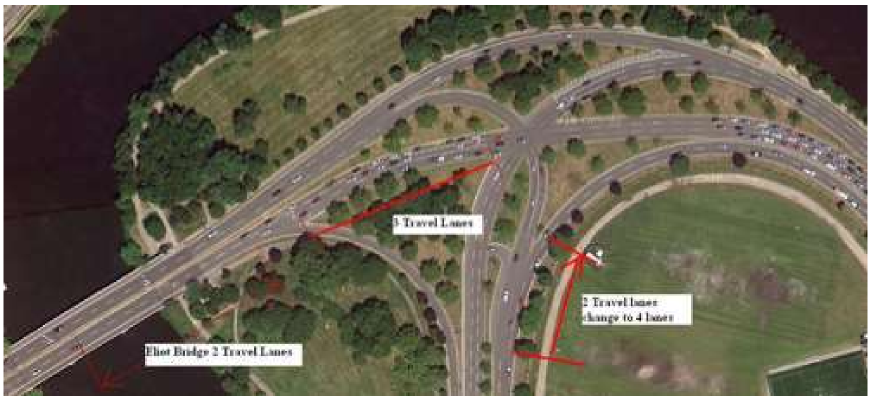
① Alignment of At-Grade Intersections

- Efforts should be made to avoid creating short-radii horizontal curves
  - since such curves result in the encroachment of drivers on sections of the opposite lanes



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Alignment of At-Grade Intersections

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② Profile of At-Grade Intersections

- Wherever possible, large changes in grade should be avoided; preferably, grades should not be > 3 %
  - Significant differences start to occur in stopping and accelerating distances for passenger cars at grades > 3%

In any case, it is not advisable to use grades higher than 6 percent at intersections

- The grade of the minor road should be altered if necessary rather than the major road
- Combination of alignment and grades at an intersection should allow motorists to easily understand the path they should take for any desired direction

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interchange

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③ Curves of At-Grade Intersections

- Main influencing factors:
  - **Angle of turn**
  - **Turning speed** [$R = u^2 / 127 (e + f)$]
  - **Design vehicle**
  - **Traffic volume**
- If turning speed is assumed < 15 mi/h (25 km/hr)
  - the curves for the pavement edges are designed to conform to at least the minimum turning path of the design vehicle.
- If turning speed is assumed > 15 mi/h
  - minimum turning radius using the design speed should be considered

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③ Curves of At-Grade Intersections

- The three types of design commonly used when turning speeds are 15 mi/h or less are:
  - **The simple curve** (an arc of a circular curve),
  - The simple curve **with taper**, and
  - **The three-centered** compound curve (three simple curves joined together and turning in the same direction).

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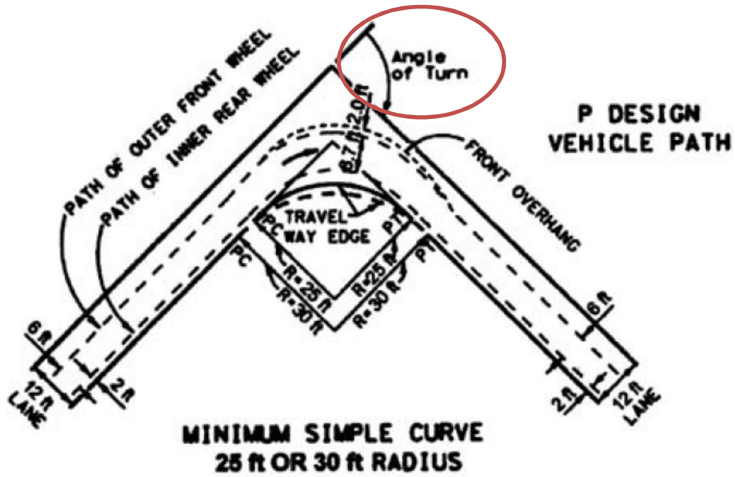
③ Curves of At-Grade Intersections

1. **Simple curve (an arc of a circular curve)**



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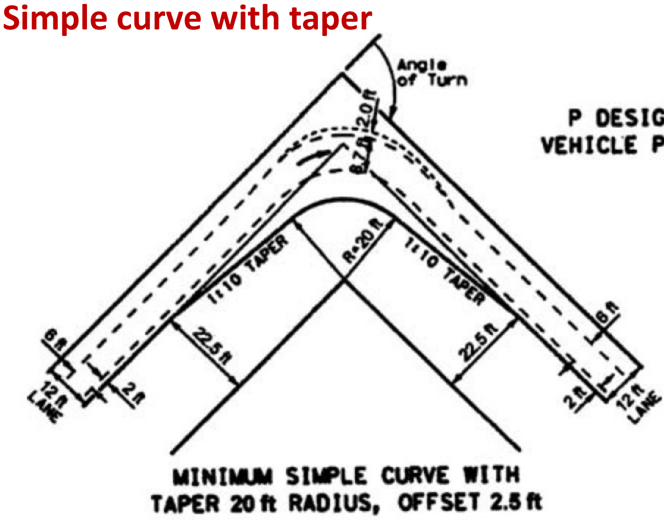
③ Curves of At-Grade Intersections

- If turning speed is assumed < 15 mi/h, three types of design commonly used

2. **Simple curve with taper**



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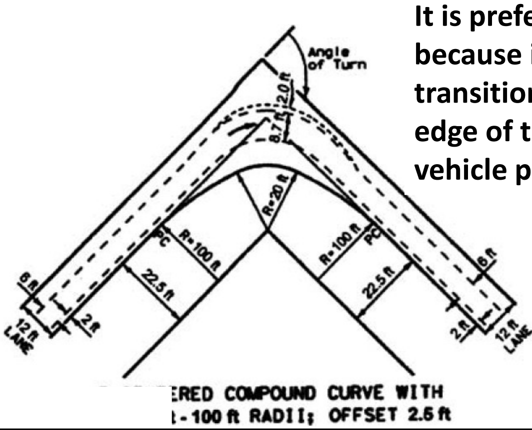
③ Curves of At-Grade Intersections

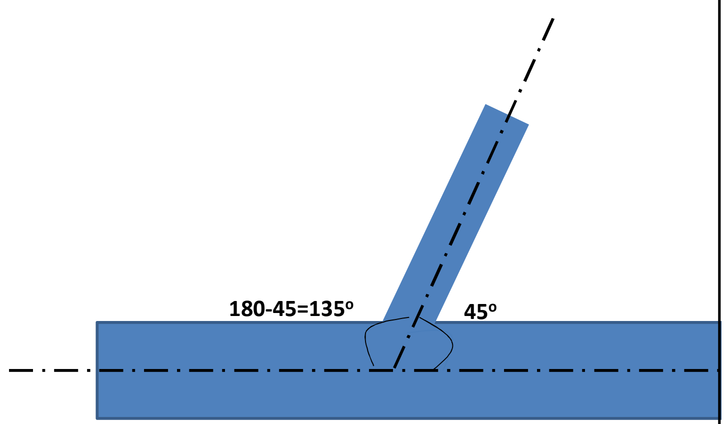
- If turning speed is assumed < 15 mi/h, three types of design commonly used

  3. **3-centered compound curve (three simple curves joined together and turning in the same direction)**



It is preferable to simple curve because it provides for a smoother transition and because the resulting edge of the pavement fits the design vehicle path more closely

Example



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③ Curves of At-Grade Intersections

Table 7.2 Minimum Edge of Pavement Design for Turns at Intersections: Simple Curves and Simple Curves with Taper

Angle of Turn (degree)	*Design Vehicle*	*Simple Curve Radius (ft)*	*Simple Curve Radius with Taper*		
			Radius (ft)	*Offset (ft)*	*Taper L:T*
30	P	60	—	—	—
	SU	100	—	—	—
	WB-40	150	—	—	—
	WB-50	200	—	—	—
	WB-62	360	220	3.0	15:1
	WB-67	380	220	3.0	15:1
	WB-100T	260	125	3.0	15:1
	WB-109D	475	260	3.5	20:1
45	P	50	—	—	—
	SU	75	—	—	—
	WB-40	120	—	—	—
	WB-50	175	120	2.0	15:1
	WB-62	230	145	4.0	15:1
	WB-67	250	145	4.5	15:1
	WB-100T	200	115	2.5	15:1
	WB-109D	—	200	4.5	20:1
60	P	40	—	—	—
	SU	60	—	—	—
	WB-40	90	—	—	—
	WB-50	150	120	3.0	15:1
	WB-62	170	140	4.0	15:1
	WB-67	200	140	4.5	15:1
	WB-100T	150	95	2.5	15:1
	WB-109D	—	180	4.5	20:1

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③ Curves of At-Grade Intersections

Table 7.3 Minimum Edge of Pavement Design for Turns at Intersections: Three-Centered Curves

Angle of Turn (degree)	*Design Vehicle*	*3-Centered Compound*		*3-Centered Compound*	
		Curve Radii (ft)	*Symmetric Offset (ft)*	*Curve Radii (ft)*	*Asymmetric Offset (ft)*
30	P	—	—	—	—
	SU	—	—	—	—
	WB-40	—	—	—	—
	WB-50	—	—	—	—
	WB-62	—	—	—	—
	WB-67	460-175-460	4.0	300-175-550	2.0-4.5
	WB-100T	220 -80-220	4.5	200- 80-300	2.5-5.0
	WB-109D	550-250-550	5.0	250-200-650	1.5-7.0
45	P	—	—	—	—
	SU	—	—	—	—
	WB-40	—	—	—	—
	WB-50	200-100-200	3.0	—	—
	WB-62	460-240-460	2.0	120-140-500	3.0-8.5
	WB-67	460-175-460	4.0	250-125-600	1.0-6.0
	WB-100T	250- 80-250	4.5	200- 80-300	2.5-5.5
	WB-109D	550-200-550	5.0	200-170-650	1.5-7.0
60	P	—	—	—	—
	SU	—	—	—	—
	WB-40	—	—	—	—
	WB-50	200- 75-200	5.5	200- 75-275	2.0-7.0
	WB-62	400-100-400	15.0	110-100-220	10.0-12.5
	WB-67	400-100-400	8.0	250-125-600	1.0-6.0
	WB-100T	250- 80-250	4.5	200- 80-300	2.0-5.5
	WB-109D	650-150-650	5.5	200-140-600	1.5-8.0

The simple curve with taper closely approximates the 3-centered curve in the field.

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Example

- **Given**:
  - Speed <15mi/hr
  - Design vehicle: WB-100T
  - Angle of turn: **45**
- Our design alternatives are:
- **From Table 7.2**: Simple Curve with Radius= 200 ft
- **From Table 7.2:** *Simple Curve Radius with Taper*
  - » *Radius:* 115 ft
  - » *Offset:* 2.5 ft
  - » *Taper*15:1
- **From Table 7.3**: Three-Centered Curves
  - » *Curve Radii (ft): (250- 80-250)*
  - » *Symmetric offset: 4.5 ft*
  - *OR*
  - » *Curve Radii (ft):(200- 80-300)*
  - » *Asymmetric offsets: 2.5-5.5*

Table 7.2 Minimum Edge of Pavement Design for Turns at Intersections: Simple Curves and Simple Curves with Taper

Angle of Turn (degree)	Design Vehicle	Simple Curve Radius (ft)	Simple Curve Radius with Taper: Radius (ft)	Offset (ft)	Taper L:T
30	P	60	–	–	–
	SU	100	–	–	–
	WB-40	150	–	–	–
	WB-50	200	–	–	–
	WB-62	360	220	3.0	15:1
	WB-67	380	220	3.0	15:1
	WB-100T	260	125	3.0	15:1
	WB-109D	475	260	3.5	20:1
45	P	50	–	–	–
	SU	75	–	–	–
	WB-40	120	–	–	–

Table 7.3 Minimum Edge of Pavement Design for Turns at Intersections: Three-Centered Curves

Angle of Turn (degree)	Design Vehicle	3-Centered Compound: Curve Radii (ft)	Symmetric Offset (ft)	3-Centered Compound: Curve Radii (ft)	Asymmetric Offset (ft)
30	P	–	–	–	–
	SU	–	–	–	–
	WB-40	–	–	–	–
	WB-50	–	–	–	–
	WB-62	–	–	–	–
	WB-67	460-175-460	4.0	300-175-550	2.0-4.5
	WB-100T	220 -80-220	4.5	200- 80-300	2.5-5.0
	WB-109D	550-250-550	5.0	250-200-650	1.5-7.0
45	P	–	–	–	–
	SU	–	–	–	–
	WB-40	–	–	–	–
	WB-50	200-100-200	3.0	–	–
	WB-62	460-240-460	2.0	120-140-500	3.0-8.5
	WB-67	460-175-460	4.0	250-125-600	1.0-6.0
	WB-100T	250- 80-250	4.5	200- 80-300	2.5-5.5
	WB-109D	550-200-550	5.0	200-170-650	1.5-7.0
60	P	–	–	–	–
	SU	–	–	–	–
	WB-40	–	–	–	–
	WB-50	200- 75-200	5.5	200- 75-275	2.0-7.0
	WB-62	400-100-400	15.0	110-100-220	10.0-12.5
	WB-67	400-100-400	8.0	250-125-600	1.0-6.0

interchange

③ Curves of At-Grade Intersections

- The minimum design for passenger cars is used only
  - at locations where the absolute minimum turns will occur, such as the intersections of local roads with major highways where only occasional turns are made
  - at intersections of two minor highways carrying low volumes
- It is recommended when conditions permit that the minimum design for the SU truck be used.

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④ Channelization of At-Grade Intersections

- ***Channelization***: the separation of conflicting traffic movements into definite paths of travel by traffic islands or pavement markings to facilitate the safe and orderly movements of both vehicles and pedestrians
- **Traffic island**: the area between traffic lanes that is used to regulate the movement of vehicles or to serve as a pedestrian refuge (Vehicular traffic is excluded from the island area)

④ Channelization of At-Grade Intersections

- A properly channelized intersection will result in
  - **Increased capacity**
  - **Enhanced safety**
  - **Increased driver confidence**
- Over-channelization should be avoided since this frequently creates confusion for the motorist and may even result in a lower operating level

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④ Channelization of At-Grade Intersections

- Channelization objectives:
  1. Direct the paths of vehicles so that not more than two paths cross at any one point
  2. Control the merging, diverging, or crossing angle of vehicles
  3. Decrease vehicle wander and the area of conflict among vehicles by reducing the amount of paved area
  4. Provide a clear indication of the proper path for different movements
  5. Give priority to the predominant movements
  6. Provide pedestrian refuge
  7. Provide separate storage lanes for turning vehicles, thereby creating space away from the path of through vehicles for turning vehicles to wait

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④ Channelization of At-Grade Intersections

- Channelization objectives:
  8. Provide space for traffic control devices so that they can be readily seen
  9. Control prohibited turns
  10. Separate different traffic movements at signalized intersections with multiple-phase signals
  11. Restrict the speeds of vehicles

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interchange

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interchange

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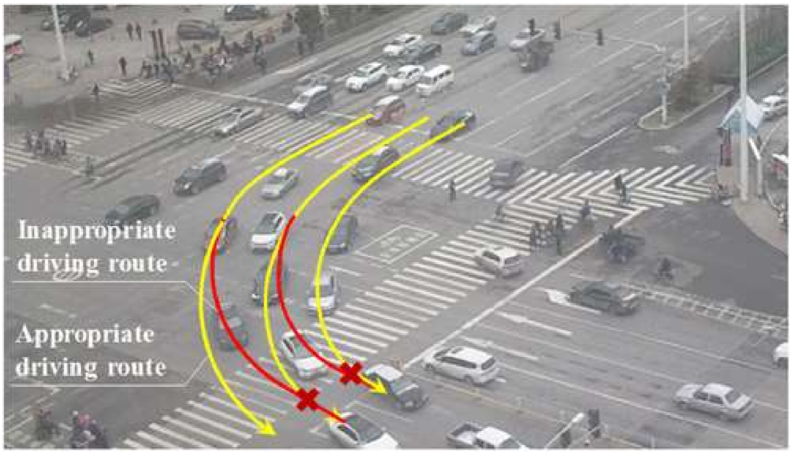

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interchange

④ Channelization of At-Grade Intersections

- Based on their physical characteristics, they are classified into:

1. **Curbed Traffic Islands: classified into mountable or barrier**
   - Used mainly in urban highways where approach speed is not excessively high and pedestrian volume is relatively high
   - Because of glare, curbed islands may be difficult to see at night

Example of a road with a median and pedestrian crossing islands.

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④ Channelization of At-Grade Intersections

1. **Traffic Islands Formed by Pavement Markings**
   - Flushed island
   - Markers include paint, thermoplastic striping, and raised retro-reflective markers
   - Preferred over curbed islands at intersections where approach speeds are relatively high, pedestrian traffic is low, and signals or sign mountings are not located on the island

④ Channelization of At-Grade Intersections

3. Islands Formed by Pavement Edges

- Usually unpaved and are mainly used at rural intersections where there is space for large intersection curves

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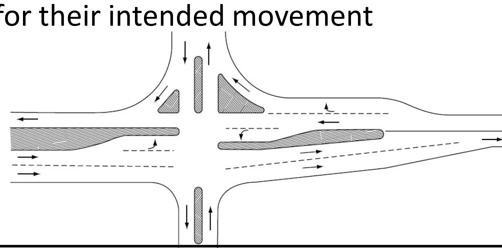
④ Channelization of At-Grade Intersections

- Based on <u>their function</u>, they are classified into:

1. Channelized islands

- They eliminate confusion to motorists at intersections with different traffic movements by guiding them into the correct lane for their intended movement



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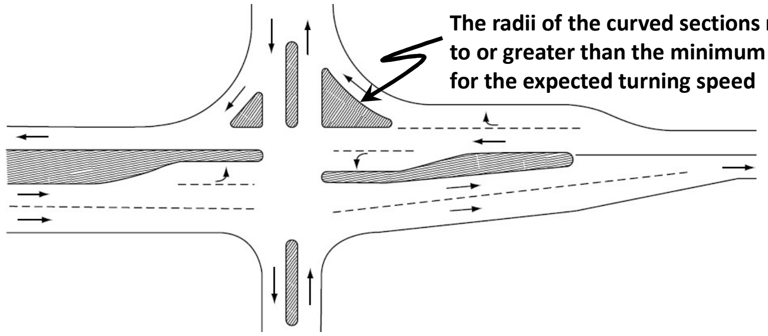
④ Channelization of At-Grade Intersections

1. Channelized islands

- The outlines of a channelized island should be nearly parallel to the lines of traffic it is channeling

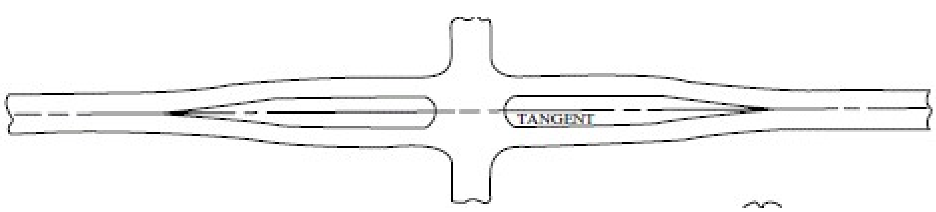


- Number of channelized islands at an intersection should be kept to a practical minimum, since the presence of several islands may cause confusion to the motorist

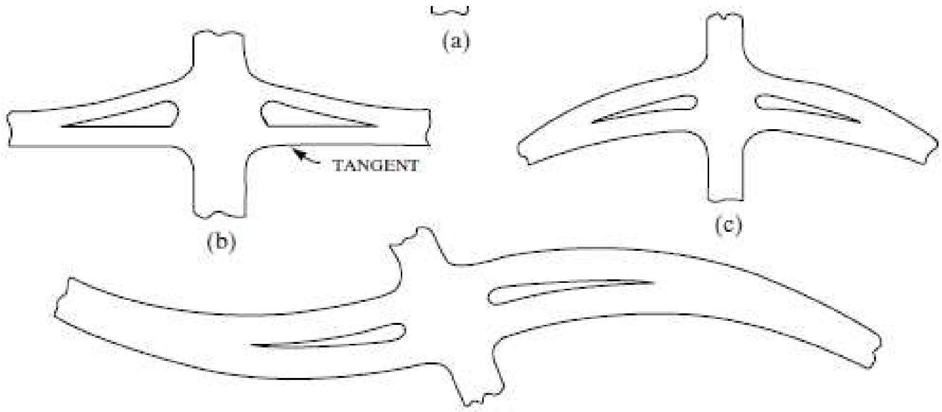
④ Channelization of At-Grade Intersections

2. Divisional islands

- They are used to alert drivers that they are approaching an intersection and to control traffic at the intersection
- They also can be used effectively to control left turns at skewed intersections
- The alignment should be designed so that the driver can traverse the intersection easily without any excessive steering



④ Channelization of At-Grade Intersections



It is sometimes necessary to use reverse curves (two simple curves with opposite curvatures, forming a compound curve) when divisional islands are introduced (particularly when the location is at a tangent)

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④ Channelization of At-Grade Intersections

3. Refuge islands: (pedestrian islands)

- They are used mainly at urban intersections to serve as refuge areas for wheelchairs and pedestrians crossing wide intersections.
- They also may be used for loading and unloading transit passengers

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④ Channelization of At-Grade Intersections

- Minimum Sizes of Islands:
  - AASHTO recommends that curbed islands have a minimum area of approximately 4.5 m^2 for urban intersections and 7 m^2 for rural intersections, although 9 m^2 ft is preferable for both
  - It is not advisable to introduce curbed divisional islands at isolated intersections on high-speed roads,
    - since this may create a hazardous situation unless the island is made visible enough to attract the attention of the driver
  - In cases where signs are located on the island, the width of the sign must be considered to ensure that the sign does not extend beyond the limits of the island

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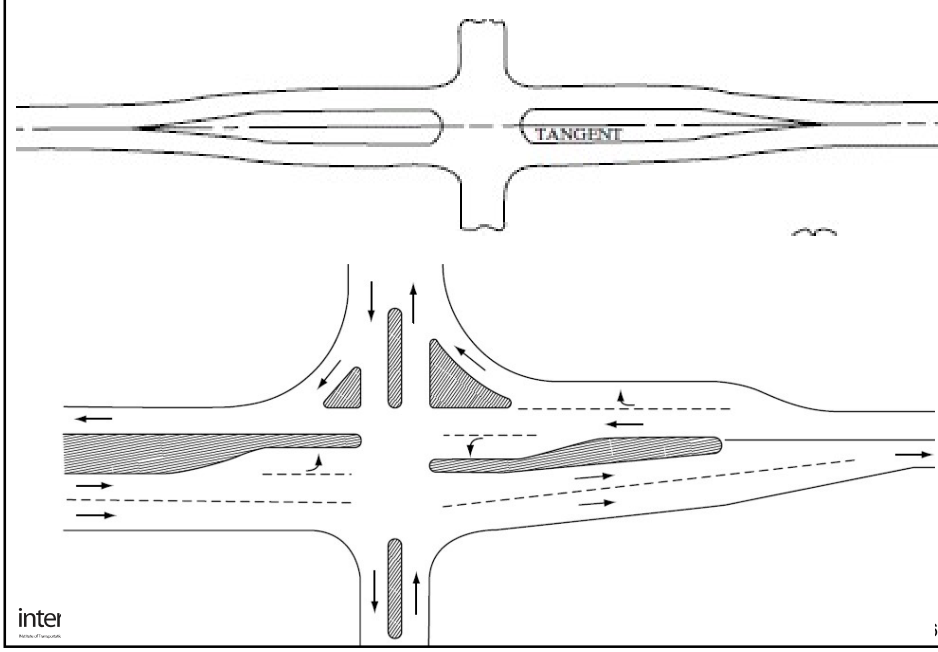
How to design the shape of an island?



inter

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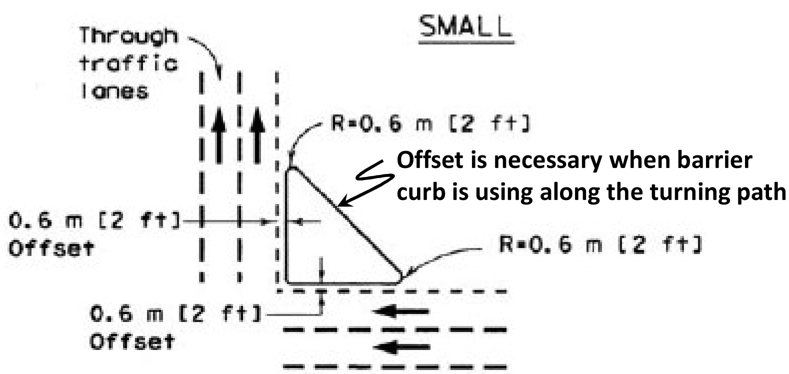
④ Channelization of At-Grade Intersections

- Location and Treatment of Approach Ends of Curbed Islands:
  - The location of a curbed island at an intersection is dictated by the edge of the through traffic lanes and the turning roadways



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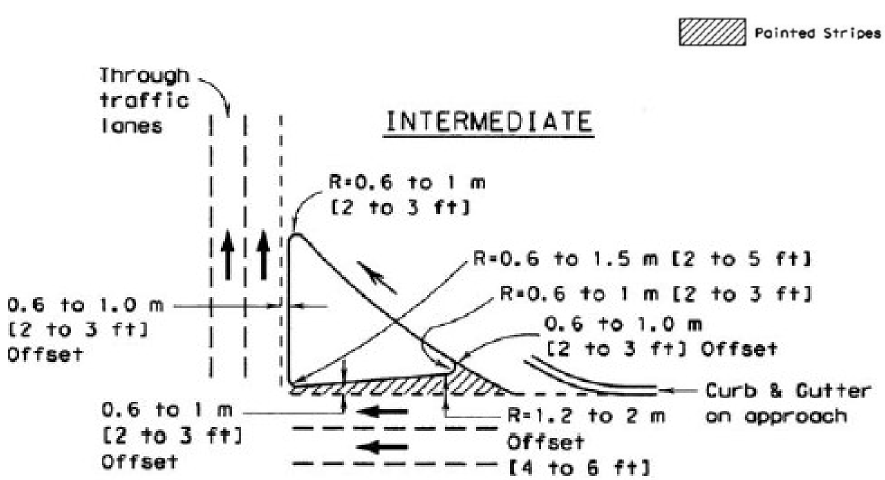
④ Channelization of At-Grade Intersections

- Location and Treatment of Approach Ends of Curbed Islands:



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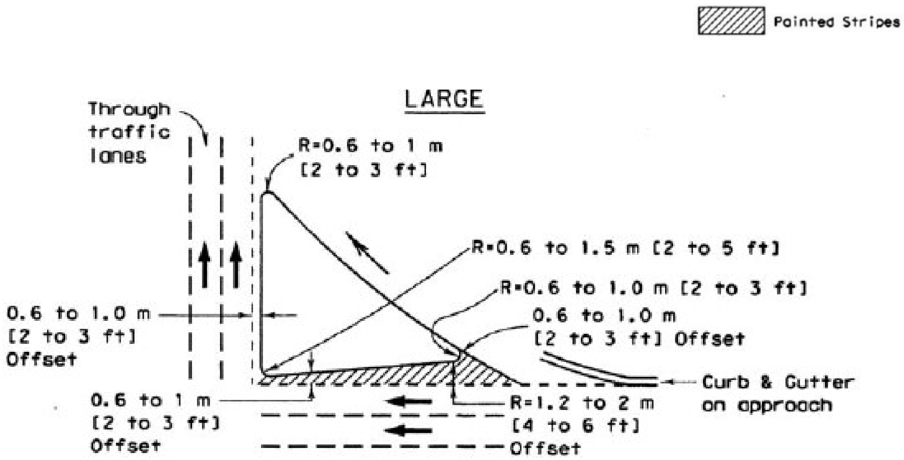
④ Channelization of At-Grade Intersections

- Location and Treatment of Approach Ends of Curbed Islands:



TRIANGULAR CURBED ISLAND ON URBAN STREETS

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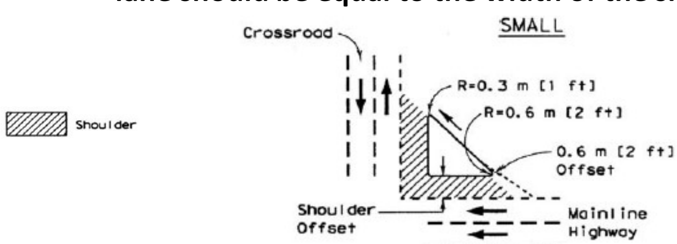
④ Channelization of At-Grade Intersections

- Location and Treatment of Approach Ends of Curbed Islands:
  - At intersections with approach shoulders but without deceleration or turn lanes,

The offset of curbed islands from the through travel lane should be equal to the width of the shoulder



Note:
Layout shown also could apply to large islands without curbs.

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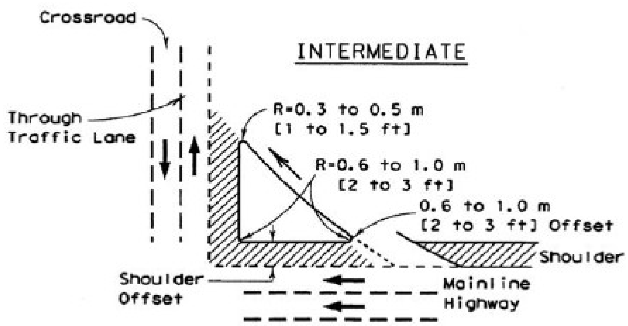
④ Channelization of At-Grade Intersections

- Location and Treatment of Approach Ends of Curbed Islands:
  - If deceleration lane precedes the curbed island, or when a gradually widened auxiliary pavement exists and speeds are within the intermediate-to-high range,
    - it is desirable to increase the offset of the nose by an additional 0.6 to 1.2 m



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⑤Minimum Pavement Widths of Turning Roadways

- In cases where vehicle speeds are expected to be greater than 15 mi/h, it is necessary to increase the pavement widths of the turning roadways
- Three classifications of pavement widths:
  - **Case I:** one-lane, one-way operation with no provision for passing a stalled vehicle
  - **Case II:** one-lane, one-way operation with provision for passing a stalled vehicle
  - **Case III:** two-lane operation, either one-way or two-way

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⑤Minimum Pavement Widths of Turning Roadways

- The pavement width for each case depends on:
  - Radius of the turning roadway
  - Characteristics of the design vehicle
- The pavement width depends on:
  - Widths of the front and rear overhangs F_A and F_B of the design vehicle,
  - Total clearance per vehicle **C**,
  - An extra width allowance due to difficulty of driving on curves **Z**,
  - Track width **U** of the vehicle as it moves around the curve.

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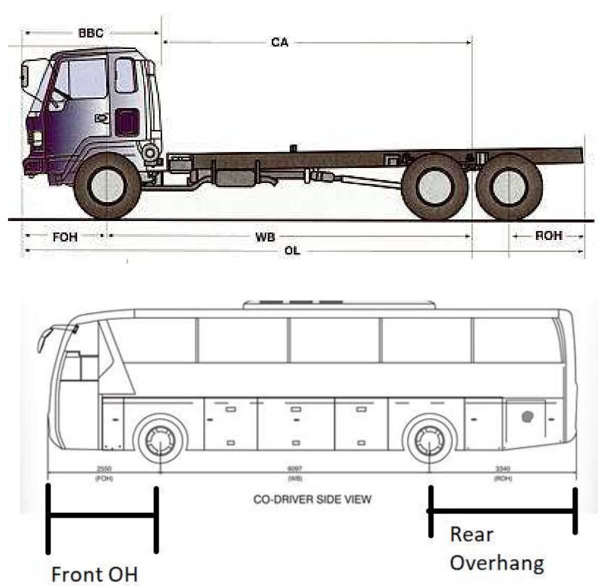

interchange

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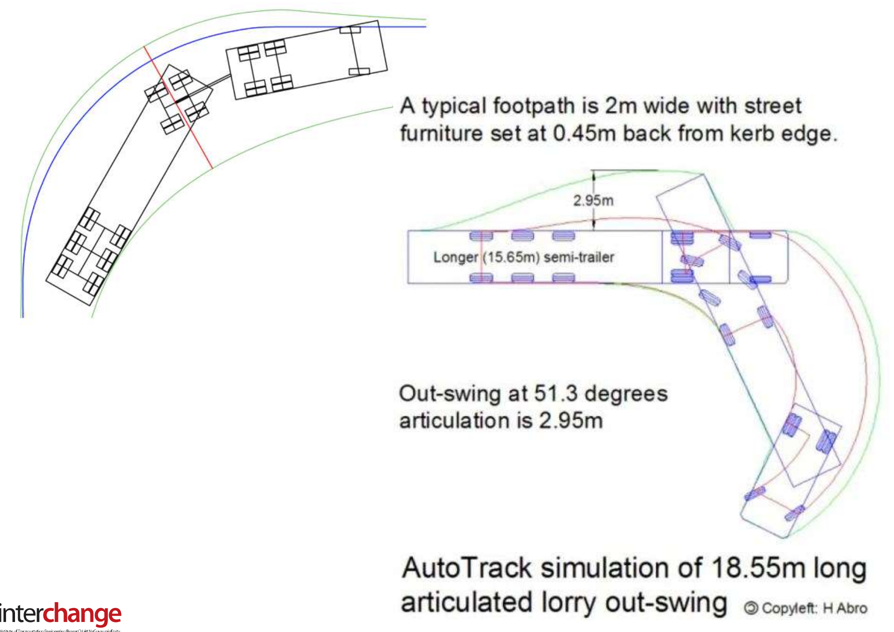

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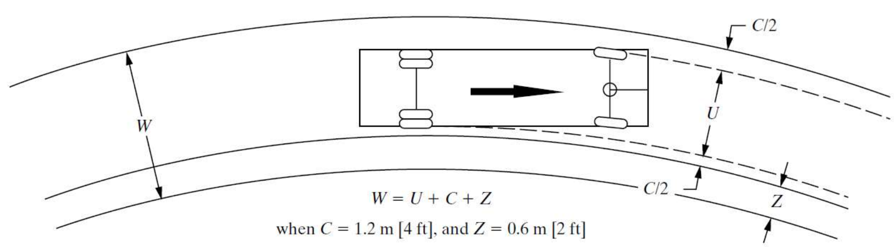
Case I: One Lane One Way Operation No Passing



$W = U + C + Z$

when $C = 1.2$ m [4 ft], and $Z = 0.6$ m [2 ft]

then $W = U + 1.8$ [$W = U + 6$]

CASE I

One−Lane One−Way Operation−No Passing

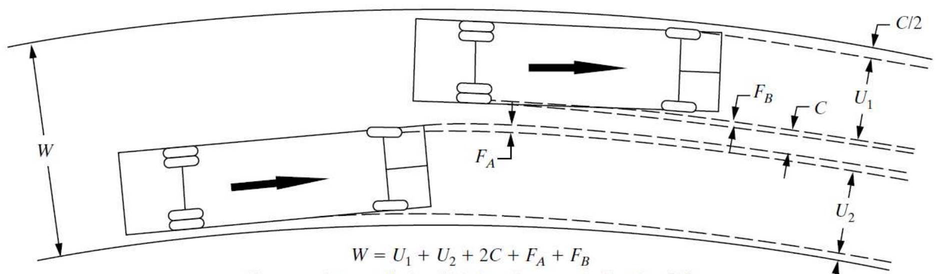
***F_A can be ignored* in Case I, as no passing maneuver is involved**

U = Track width of vehicle (out−to−out tires), m [ft]
F_A = Width of front overhang, m [ft]
F_B = Width of rear overhang, m [ft]

C = Total lateral clearance per vehicle, m [ft]
Z = Extra width allowance due to difficulty of driving on curves, m [ft]

interchange

Case II: One Lane One Way Operation Provision for Passing Stalled Vehicle



$W = U_1 + U_2 + 2C + F_A + F_B$

Since passing a stalled vehicle is at low speed, $Z = 0$ m [ft];
and C is assumed half that for Cases I & III, or $C = 0.6$ m [2 ft]
then $W = U_1 + U_2 + F_A + F_B + 1.2$ [$W = U_1 + U_2 + F_A + F_B + 4$]

CASE II

One–Lane One–Way Operation Provision for Passing Stalled Vehicle

U = Track width of vehicle (out–to–out tires), m [ft]
F_A = Width of front overhang, m [ft]
F_B = Width of rear overhang, m [ft]

C = Total lateral clearance per vehicle, m [ft]
Z = Extra width allowance due to difficulty of driving on curves, m [ft]

interchange

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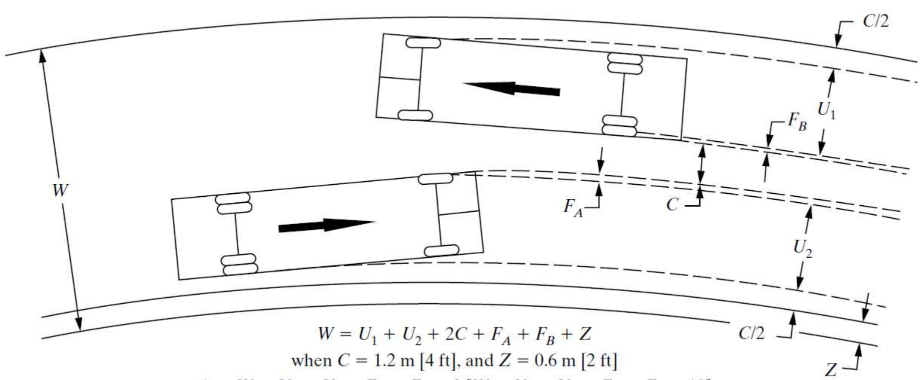
⑤Case III: Two Lane Operation One or Two Way



$W = U_1 + U_2 + 2C + F_A + F_B + Z$

when $C = 1.2$ m [4 ft], and $Z = 0.6$ m [2 ft]
then $W = U_1 + U_2 + F_A + F_B + 3$ [$W = U_1 + U_2 + F_A + F_B + 10$]

CASE III

Two–Lane Operation–One or Two Way

U = Track width of vehicle (out–to–out tires), m [ft]
F_A = Width of front overhang, m [ft]
F_B = Width of rear overhang, m [ft]

C = Total lateral clearance per vehicle, m [ft]
Z = Extra width allowance due to difficulty of driving on curves, m [ft]

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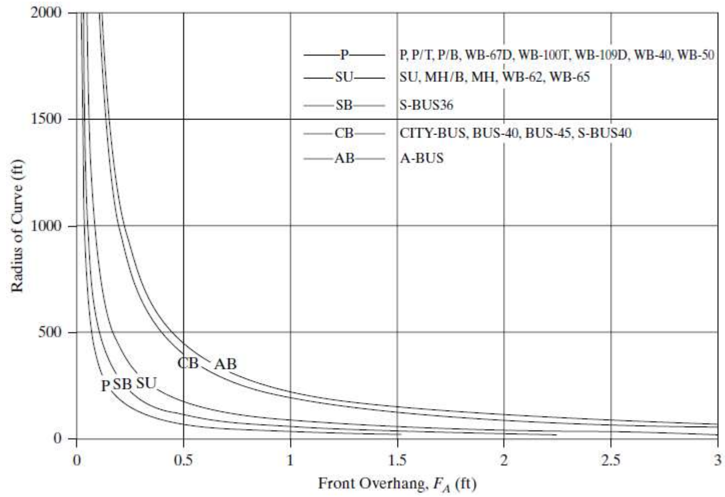
⑤Minimum Pavement Widths of Turning Roadways

- Values for the front overhang $\mathbf{F_A}$ for different vehicle types can be obtained directly from Figure 7.18



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⑤Minimum Pavement Widths of Turning Roadways

- The width of the rear overhang $\mathbf{F_B}$ is usually taken as
  - 0.15 m (0.5 ft) for passenger cars
  - 0 m for truck vehicles
- The lateral clearance **C** can be taken as:
  - 4 ft (1.2 m) for **Case I**
  - 2 ft (0.6 m) for the stopped vehicle and 2 ft for the passing vehicle in **Case II**
  - 4 ft (1.2 m) for **Case III**
- The extra width allowance **Z** is estimated as:

Z = extra width allowance to compensate for the difficulty in maneuvering (ft)
v = design speed (mi/h)
R = radius of curve (ft)

$$Z = \frac{v}{\sqrt{R}}$$

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⑤Minimum Pavement Widths of Turning Roadways

- The track width **U** for passenger cars and single-unit trucks is given as:

$$U = u + R - \sqrt{(R^2 - \sum L_i^2)}$$

U = track width on curve (ft)
u = track width on tangent (out-to-out of tires) (ft)
R = radius of curve or turn (ft)
L_i = wheelbase of design vehicle between consecutive axles or (sets of tandem axles) and articulation points (ft)

⑤Minimum Pavement Widths of Turning Roadways

- Table 7.4 gives values for the required pavement width

Table 7.4 Derived Pavement Widths for Turning Roadways for Different Design Vehicles[1]

U.S. CUSTOMARY

Radius on inner edge of pavement R (ft)	P	SU	BUS-40	BUS-45	CITY-BUS	S-BUS36	S-BUS40	A-BUS	WB-40	WB-50	WB-62	WB-65	WB-67D	WB-100T	WB-109D	MH	P/T	P/B	MH/B
Case I, One-Lane, One-Way Operation No Provision for Passing a Stalled Vehicle																			
50	13	18	22	23	21	19	18	22	23	32	43	49	29	37	—	18	19	18	21
75	13	17	19	20	19	17	17	19	20	25	29	32	23	27	43	17	17	17	19
100	13	16	18	19	18	16	16	18	18	22	25	27	21	24	34	16	16	16	17
150	12	15	17	17	17	16	15	17	17	19	21	22	19	21	27	15	16	15	16
200	12	15	16	17	16	15	15	16	16	18	20	20	18	19	23	15	15	15	16
300	12	15	16	16	16	15	15	16	15	17	18	18	17	17	20	15	15	15	15
400	12	15	16	16	16	15	15	16	15	17	18	18	17	17	20	15	15	15	15
500	12	15	16	16	16	15	15	16	15	17	18	18	17	17	20	15	15	15	15
Tangent	12	14	15	15	15	14	14	15	14	15	15	15	15	15	15	14	14	14	14
CASE II One−Lane One−Way Operation Provision for Passing Stalled Vehicle																			
50	20	30	39	42	38	31	32	40	39	56	79	93	50	67	—	30	30	28	36
75	19	27	32	35	32	27	28	34	32	42	52	56	39	47	79	27	27	26	30
100	18	25	30	31	29	25	26	30	29	36	43	46	34	40	60	25	25	24	28
150	18	23	27	28	27	23	24	27	26	31	35	37	29	33	45	23	23	23	25
200	17	22	25	26	25	23	23	26	24	28	32	33	27	30	39	22	22	22	24
300	17	22	24	24	24	22	22	24	23	26	28	29	25	27	33	22	22	21	23
400	17	21	23	24	23	21	21	23	22	25	26	27	24	25	30	21	21	21	22
500	17	21	23	23	23	21	21	23	22	24	25	26	23	25	28	21	21	21	21
Tangent	17	20	21	21	21	20	20	21	20	21	21	21	21	21	21	20	20	20	20
CASE III Two−Lane Operation−One or Two Way																			
50	26	36	45	48	44	37	38	46	45	62	85	99	56	73	—	36	36	34	42
75	25	33	38	41	38	33	34	40	38	48	58	62	45	53	85	33	33	32	36
100	24	31	36	37	35	31	32	36	35	42	49	52	40	46	66	31	31	30	34
150	24	29	33	34	33	29	30	33	32	37	41	43	35	39	51	29	29	29	31
200	23	28	31	32	31	29	29	32	30	34	38	39	33	36	45	28	28	28	30
300	23	28	30	30	30	28	28	30	29	32	34	35	31	33	39	28	28	27	29
400	23	27	29	30	29	27	27	29	28	31	32	33	30	31	36	27	27	27	28
500	23	27	29	29	29	27	27	29	28	30	31	32	29	31	34	27	27	27	27
Tangent	23	26	27	27	27	26	26	27	26	27	27	27	27	27	27	26	26	26	26

⑤Minimum Pavement Widths of Turning Roadways

- Pavement widths are **seldom designed for a single vehicle type**, since the highway should be capable of accommodating different types of vehicles, especially when provision is made for passing
- Design of the pavement width is therefore based on three types of traffic conditions
  - **Traffic Condition A:** **Passenger vehicles** are predominant, but this traffic condition also provides some consideration for the occasional SU truck
  - **Traffic Condition B:** Proportion of **SU vehicles** warrants this vehicle type to be the design vehicle but it allows for the accommodation of some tractor-trailer combination trucks (5 to 10%)
  - **Traffic Condition C:** Design vehicle is **WB-12 or WB-15 (WB-40 or WB-50)**

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⑤Minimum Pavement Widths of Turning Roadways

Table 7.5 Design Widths of Pavements for Turning Roadways

U.S. CUSTOMARY									
Radius on inner edge of pavement R(ft)	Case I One-Lane, One-Way Operation—No Provision for Passing a Stalled Vehicle			Case II One-Lane, One-Way Operation—with Provision for Passing a Stalled Vehicle			Case III Two-Lane Operation—Either One-Way or Two-Way		
	Design Traffic Conditions								
	A	B	C	A	B	C	A	B	C
50	18	18	23	20	26	30	31	36	45
75	16	17	20	19	23	27	29	33	38
100	15	16	18	18	22	25	28	31	35
150	14	15	17	18	21	23	26	29	32
200	13	15	16	17	20	22	26	28	30
300	13	15	15	17	20	22	25	28	29
400	13	15	15	17	19	21	25	27	28
500	12	15	15	17	19	21	25	27	28
Tangent	12	14	14	17	18	20	24	26	26
Width Modification Regarding Edge Treatment									
No stabilized shoulder	None			None			None		
Sloping curb	None			None			None		
Vertical curb: One side / Two sides	Add 1 ft / Add 2 ft			None / Add 1 ft			Add 1 ft / Add 2 ft		
Stabilized shoulder, one or both sides	Lane width for conditions B&C on tangent may be reduced to 12 ft where shoulder is 4 ft or wider			Deduct shoulder width; minimum pavement width as under Case I			Deduct 2 ft where shoulder is 4 ft or wider		

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Mountable / Sloping Curb

–Vertical Curb

interchange

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⑤Minimum Pavement Widths of Turning Roadways

Design Vehicles in Combination

Table 7.6 Design Vehicles in Combination

(a) Design Vehicles in Combination that Provide the Full Clear Width (*C*)

	Design Traffic Condition		
Case	*A*	*B*	*C*
I	P	SU	WB-40
II	P-P	P-SU	SU-SU
III	P-SU	SU-SU	WB-40-WB-40

(b) Larger Vehicles that Can Be Operated

	Design Traffic Condition		
Case	*A*	*B*	*C*
I	WB-40	WB-40	WB-50
II	P-SU	P-WB-40	SU-WB-40
III	SU-WB-40	WB-40-WB-40	WB-50-WB-50

SOURCE: *A Policy on Geometric Design of Highways and Streets*, The American Association of State Highway and Transportation Officials, Washington, D.C., 2004. Used with permission.

This will result in reduced clearance between vehicles that will vary from about one-half the value of *C for sharper curves to nearly the full value* of *C for flatter curves.*

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Example 7.1

Example 7.1 Determining the Width of a Turning Roadway at an Intersection

A ramp from an urban expressway with a design speed of 30 mi/h connects with a local road forming a T intersection. An additional lane is provided on the local road to allow vehicles on the ramp to turn right onto the local road without stopping. The turning roadway has a mountable curb on one side and will provide for a one-lane, one-way operation with provision for passing a stalled vehicle. Determine the width of the turning roadway if the predominant vehicles on the ramp are single-unit trucks but give some consideration to semitrailer vehicles. Use 0.08 for the superelevation.

interchange

Solution:

- Determine the minimum radius of the curve.
  Because the speed is greater than 15 mi/h, use Eq. 3.33 of Chapter 3 and a value of 0.20 for f_s (from Table 3.3):

$$R = \frac{u^2}{15(e + f_s)} = \frac{30^2}{15(0.08 + 0.2)} = 214.29 \text{ ft}$$

  Use 215 ft.

- Determine the type of operation and traffic condition.
  The operational requirements, one-lane, one-way with provision for passing a stalled vehicle require Case II operation.
  The traffic condition, single-unit trucks but with some consideration given to semitrailer vehicles, requires Traffic Condition B.

interchange

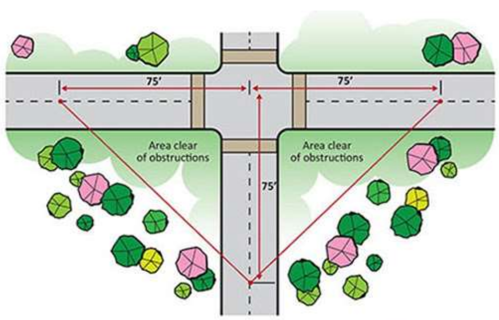
- Determine the turning roadway width.
  Use Table 7.5, with $R = 212$ ft, Traffic Condition B, and Case II.

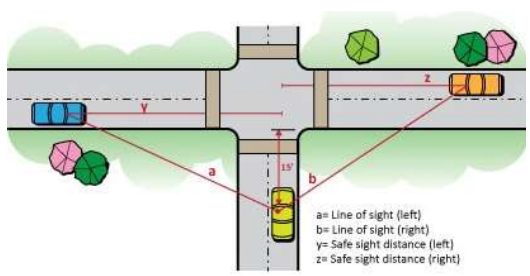
$$\text{Pavement width} = 20 \text{ ft}$$

Since the turning roadway has a mountable curb only on one side, no modification to the width is required.

interchange

⑥Sight Distance at Intersections





⑥Sight Distance at Intersections

- High crash potential can be reduced by providing sight distances that allow drivers to have an unobstructed view of the entire intersection at a distance great enough to permit control of the vehicle
- Two types of sight triangles:
  1. **Approach sight triangles**: It allows for the drivers on both the major roads and minor roads to see approaching intersecting vehicles in sufficient time to avoid a potential collision by reducing the vehicle's speed or by stopping.
  2. **Departure sight triangles**: It allows for the driver of a stopped vehicle on the minor road to enter or cross the major road without conflicting with an approaching vehicle from either direction of the major road

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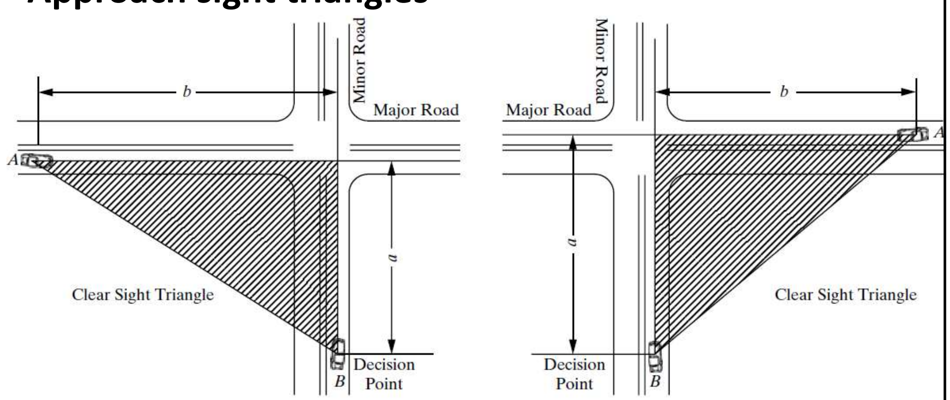
⑥Sight Distance at Intersections

- **Approach sight triangles**



(a) Approach Sight Triangles
(uncontrolled or yield-control)

- It allows for the drivers on both the major roads and minor roads to see approaching intersecting vehicles in sufficient time to avoid a potential collision by reducing the vehicle's speed or by stopping

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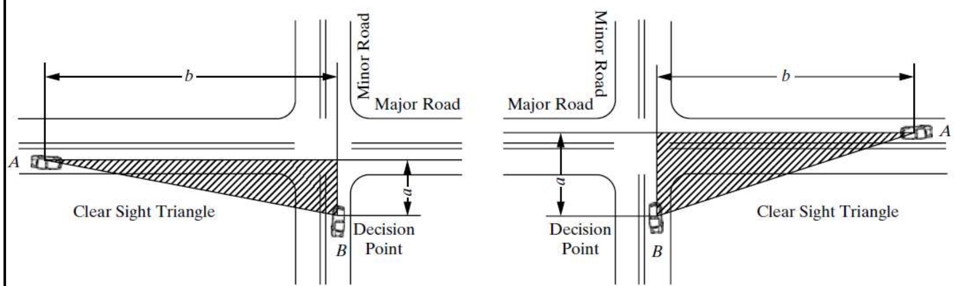
⑥Sight Distance at Intersections

- **Departure sight triangles**



(b) Departure Sight Triangles
(stop control)

- It allows for the driver of a stopped vehicle on the minor road to enter or cross the major road without conflicting with an approaching vehicle from either direction of the major road

⑥Sight Distance at Intersections

- A sight obstruction is considered as an object having a minimum height of 4.35 ft (1.33 m) that can be seen by a driver with an eye height of:
  - 3.5 ft (1.00 m) for a passenger car
  - 7.6 ft (2.3 m) for truck

- The lengths of the legs of the sight triangle depends on:
  - Major road speed
  - Minor road speed
  - Type of control

⑥Sight Distance at Intersections

- There are four cases for at-grade intersections:
  - **Case A**: With no control
  - **Case B**: With stop control on the minor road
  - **Case C**: With yield control on the minor road
  - **Case D**: With traffic signal control

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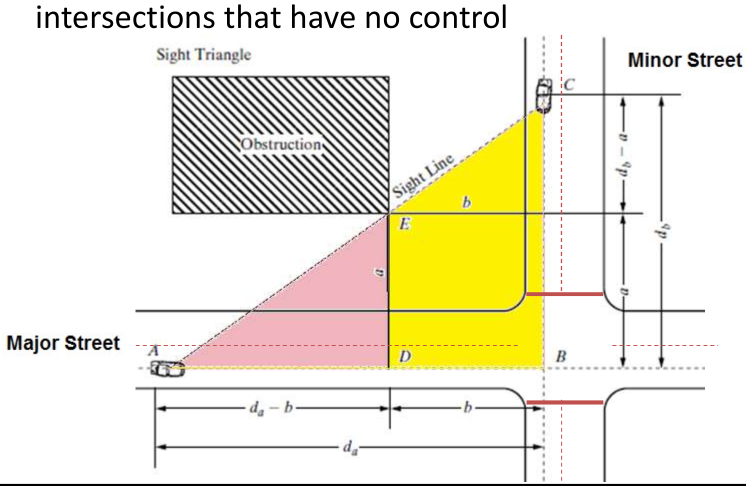
⑥Sight Distance at Intersections

- **Case A**: With no control
  - AASHTO has noted that drivers tend to decrease their speeds to about 50% of their mid-block speed as they approach intersections that have no control



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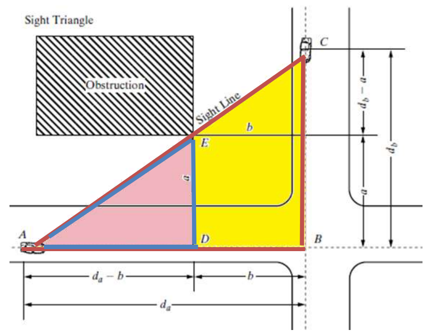
⑥Sight Distance at Intersections

- **Case A**: With no control
  - From triangle similarity:

From Table 7.7

$$\frac{d_b}{d_a} = \frac{a}{d_a - b}$$



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⑥Sight Distance at Intersections

- **Case A**: With no control

Table 7.7 Suggested Lengths and Adjustments of Sight-Triangle Leg Case A—No Traffic Control

Design Speed (mi/h)	*Length of Leg (ft)*
15	70
20	90
25	115
30	140
35	165
40	195
45	220
50	245
55	285
60	325
65	365
70	405
75	445
80	485

(a)

it should be noted that these distances tend to be lower than stopping sight distance because drivers tend to reduce their speeds as they approach intersections with no controls

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⑥Sight Distance at Intersections

- **Case A**: With no control

Table 7.7 Suggested Lengths and Adjustments of Sight-Triangle Leg Case A—No Traffic Control

Approach Grade (%)	*Design Speed (mi/h)*													
	15	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*55*	*60*	*65*	*70*	*75*	*80*
−6	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2
−5	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2
−4	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
−3 to 3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
+4	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
+5	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
+6	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

(b)

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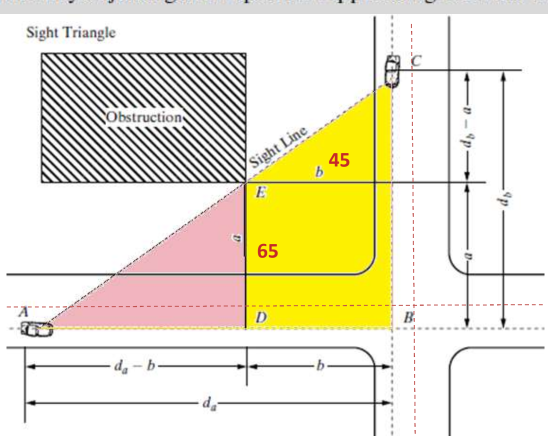
⑥Sight Distance at Intersections

Example 7.2 Computing Speed Limit on a Local Road

A tall building is located 45 ft from the centerline of the right lane of a local road (b in Figure 7.20) and 65 ft from the centerline of the right lane of an intersecting road (a in Figure 7.20). If the maximum speed limit on the intersecting road is 35 mi/h, what should the speed limit on the local road be such that the minimum sight distance is provided to allow the drivers of approaching vehicles to avoid imminent collision by adjusting their speeds? Approach grades are 2%.



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Solution:

- Determine the distance on the local road at which the driver first sees traffic on the intersecting road.

  Speed limit on intersecting road = 35 mi/h

  Distance required on intersecting road (d_a) = 165 ft (from Table 7.7)

  Calculate the distance available on local road by using Eq. 7.4

$$d_b = a\frac{d_a}{d_a - b}$$

$$= 65\frac{165}{165 - 45}$$

$$= 89.37 \text{ ft}$$

- Determine the maximum speed allowable on the local road.

  The maximum speed allowable on local road is 20 mi/h (from Table 7.7). No correction is required for the approach grade as it is less than 3%.

interchange

Table 7.7 Suggested Lengths and Adjustments of Sight-Triangle Leg Case A—No Traffic Control

Design Speed (mi/h)	*Length of Leg (ft)*
15	70
20	90
25	115
30	140
35	165
40	195
45	220
50	245
55	285
60	325
65	365
70	405
75	445
80	485

(a)

interchange

⑥Sight Distance at Intersections

- **Case C**: With yield control on the minor road
  - **Sight Distance Requirement for Crossing a Yield Controlled Intersection from a Minor Road**
  - Assumption made is similar to that used for the no-control maneuver in Case A, but with the following modifications:
    - Drivers on minor roads tend to decelerate to 60 percent of the minor road design
    - The rate of deceleration is 5 ft /sec^2 (1.5 m/sec^2)
    - **The time t_g to cross the intersection should include the time taken for the vehicle to travel from the decision point where the deceleration begins to where the speed is reduced to 60 percent of the minor road design speed**
    - The vehicle then travels at the reduced speed until it crosses and clears the intersection

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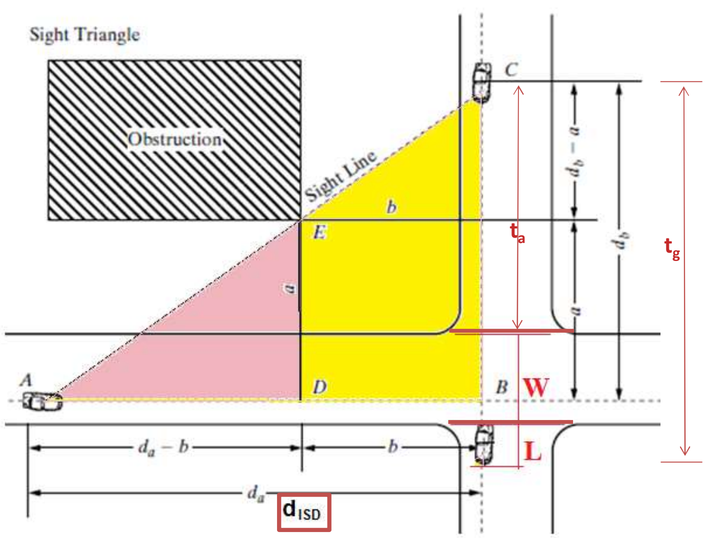

interchange

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⑥Sight Distance at Intersections

- **Case C**: With yield control on the minor road
  - The length of the sight distance (d_{ISD}):

$$t_g = t_a + (w + L_a)/0.88v_{\text{minor}}$$

$$d_{\text{ISD}} = 1.47v_{\text{major}}t_g$$

$\boxed{d_{ISD} = d_a}$

t_g = travel time to reach and clear the intersection (sec)
t_a = travel time to reach the major road from the decision point for a vehicle that does not stop
w = width of the intersection to be crossed (ft)
L_a = length of design vehicle (ft)
v_{minor} = design speed of minor road (mi/h)
v_{major} = design speed of major road (mi/h)

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⑥Sight Distance at Intersections

- **Case C**: With yield control on the minor road

$$t_g = t_a + (w + L_a)/0.88v_{\text{minor}} \qquad d_{\text{ISD}} = 1.47v_{\text{major}}t_g$$

Table 7.9 Case C1—Crossing Maneuvers from Yield-Controlled Approaches—Length of Minor Road Leg and Travel Times

Minor-Road Approach			Travel Time t_g (seconds)	
Design Speed (mi/h)	*Length of Leg[1] (ft)* d_b	*Travel Time $t_a^{1,2}$ (seconds)*	*Calculated Value*	*Design Value[3,4]*
15	75	3.4	6.7	6.7
20	100	3.7	6.1	6.5
25	130	4.0	6.0	6.5
30	160	4.3	5.9	6.5
35	195	4.6	6.0	6.5
40	235	4.9	6.1	6.5
45	275	5.2	6.3	6.5
50	320	5.5	6.5	6.5
55	370	5.8	6.7	6.7
60	420	6.1	6.9	6.9
65	470	6.4	7.2	7.2
70	530	6.7	7.4	7.4
75	590	7.0	7.7	7.7
80	660	7.3	7.9	7.9

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It should be noted that for the values in Table 7.9:

- For minor-road approach grades that exceed 3 percent, multiply the distance (d_b) or the time (t_a) in this table by the appropriate adjustment factor from Table 7.7.
- t_g values shown are for a passenger car crossing a two-lane highway with no median and grades 3 percent or less.
  - **If actual conditions are different, use the equation.**

interchange

⑥Sight Distance at Intersections

- **Case C**: With yield control on the minor road
  - Length of the sight distance (d_{ISD}) is estimated in Table 7.10

Table 7.10 Length of Sight Triangle Leg along Major Road—Case C1—Crossing Maneuver at Yield-Controlled Intersection

Major Road Design Speed (mi/h)	*Stopping Sight Distance (ft)*	*Minor-Road Design Speed (mi/h)*							
		15	*20–50*	*55*	*60*	*65*	*70*	*75*	*80*
15	80	150	145	150	155	160	165	170	175
20	115	200	195	200	205	215	220	230	235
25	155	250	240	250	255	265	275	285	295
30	200	300	290	300	305	320	330	340	350
35	250	345	335	345	360	375	385	400	410
40	305	395	385	395	410	425	440	455	465
45	360	445	430	445	460	480	490	510	525
50	425	495	480	495	510	530	545	570	585
55	495	545	530	545	560	585	600	625	640
60	570	595	575	595	610	640	655	680	700
65	645	645	625	645	660	690	710	740	755
70	730	690	670	690	715	745	765	795	815
75	820	740	720	740	765	795	795	850	875
80	910	790	765	790	815	850	850	910	930

⑥Sight Distance at Intersections

- **Case C**: With yield control on the minor road
  - It should be noted that these values are for a passenger car as the design vehicle, and approach grades of 3 percent or less
    - **If actual conditions are different, use the equation.**
    - Appropriate corrections should be done when the grade is higher than 3 percent using (Table 7.7b)

Example 7.5 Determining the Minimum Sight Distance for Crossing at an Intersection with Yield Control

An urban two-lane minor road crosses a four-lane divided highway with a speed limit of 55 mi/h. If the minor road has a speed limit of 35 mi/h and the intersection is controlled by a yield sign on the minor road, determine the sight distance from the intersection that is required along the major road such that the driver of a vehicle on the minor road can safely cross the intersection. The following conditions exist at the intersection.

Major road lane width = 11 ft
Median width = 8 ft
Design vehicle on minor road is a passenger car length = 22 ft
Approach grade on minor road = 3%.

Solution: Use Eq. 7.6 to determine time (t_a) as the travel time to reach and clear the intersection.

$$t_g = t_a + (w + L_a)/0.88v_{min}$$

t_a = 4.6 sec for passenger vehicles from Table 7.9
w = (4 × 11 + 8) = 52 ft
t_g = 4.6 + (52 + 22)/(0.88 × 35)
= 7.0 sec

Use Eq. 7.7 to determine the length of the sight on the major road.

$$d_{ISD} = 1.47v_{major}t_g$$
$$= 1.47 \times 55 \times 7.0 = 566 \text{ ft}$$

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Homework

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Intersection Design