

Intersection Design & Control

- Definition

- **An intersection is defined as the general area where two or more highways join or cross**
- **Intersections are the most important part of a highway facility since efficiency, safety, speed, cost of operation and capacity depend on their design**

Intersections

- General Design Considerations
 - Human Factors
 - Driving habits, decision and reaction time, pedestrian and bicyclist habits, etc.
 - Traffic Considerations
 - Design and actual capacity, size of vehicles, vehicle speeds, transit, crash experience, traffic volumes, etc.
 - Physical Elements
 - Alignment, sight distance, traffic control, crosswalks, lighting, angle, etc.
 - Economic factors
 - Energy consumption, costs of improvements, adjacent properties, etc.

Intersections

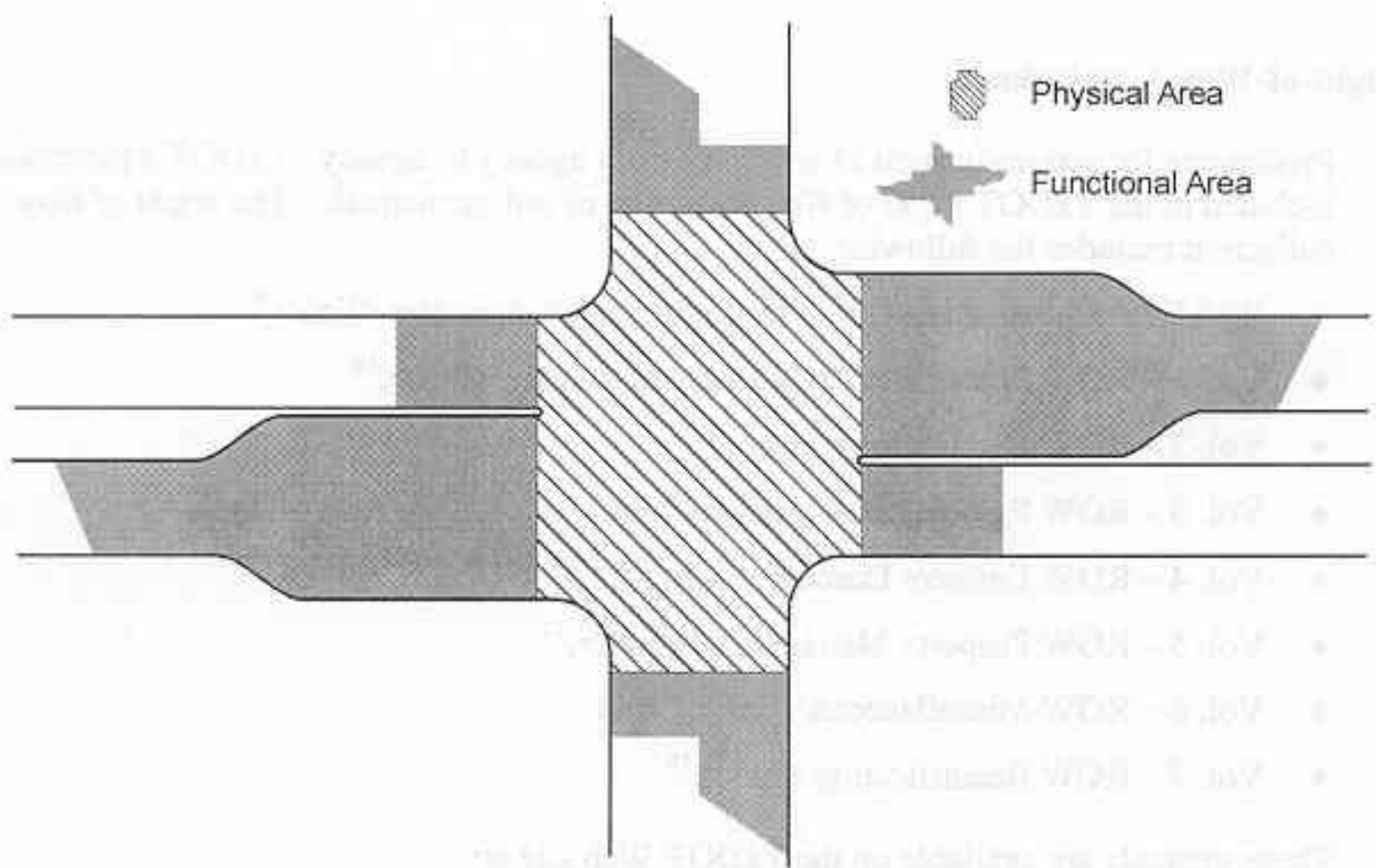


Figure 1-7. Functional Area of an Intersection.¹⁷

General type of highway crossings

1) At-grade intersections



2) Grade separation without ramps



3) Interchanges



Basic Principles of Intersections

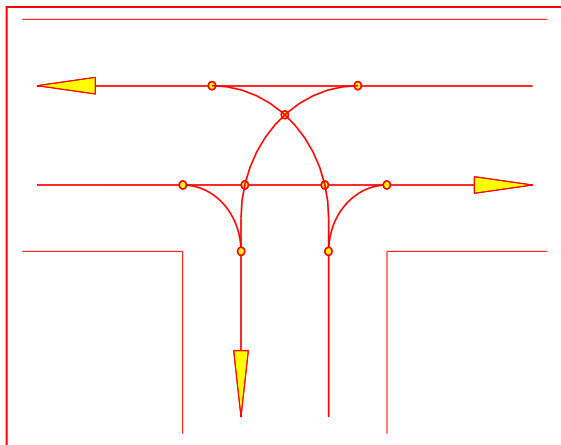
- Reduce the number of conflict points
- Minimize severity of potential conflicts
- Provide for smooth flow of traffic
- Consider both vehicles and pedestrians
- Avoid multiple and compound merging and diverging

Intersection – Design Controls

- Primary controls:
 - Functional class of roadways
 - Topography and environment (manmade and natural)
- Secondary controls:
 - Design speed
 - Design vehicles
 - Traffic Characteristics (design volumes, level of service)

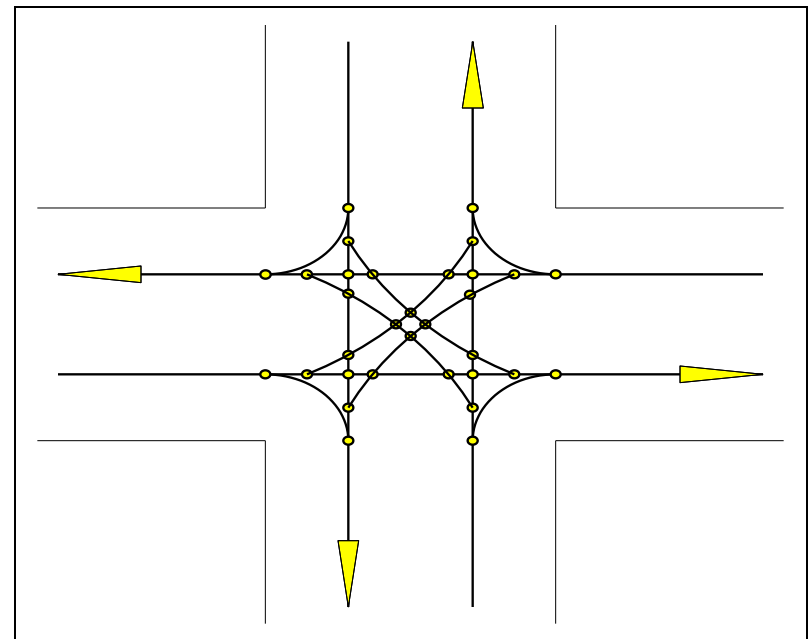
Conflict Points

3-leg intersection



Crossing Points

4-leg intersection



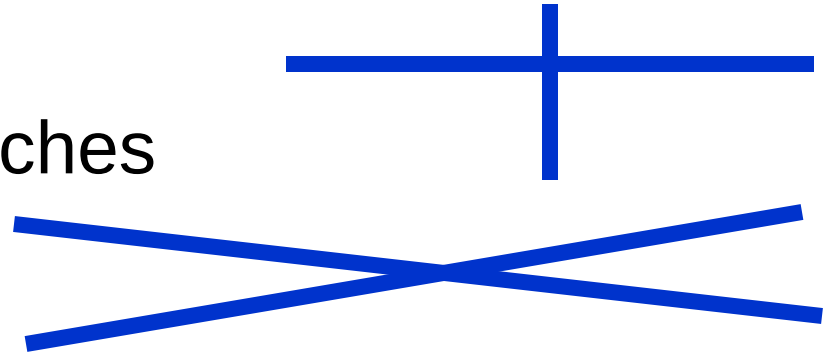
Diverging Points

Merging Points

General Considerations

For Horizontal Alignment

- 90° intersection of approaches
- Skewed (Visibility)

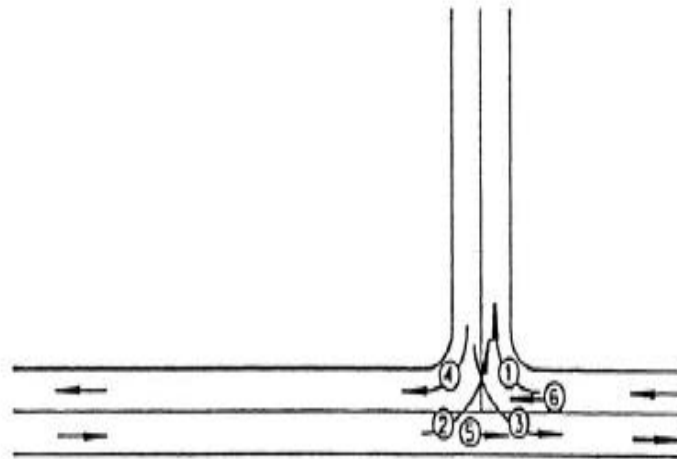


For Vertical Alignment

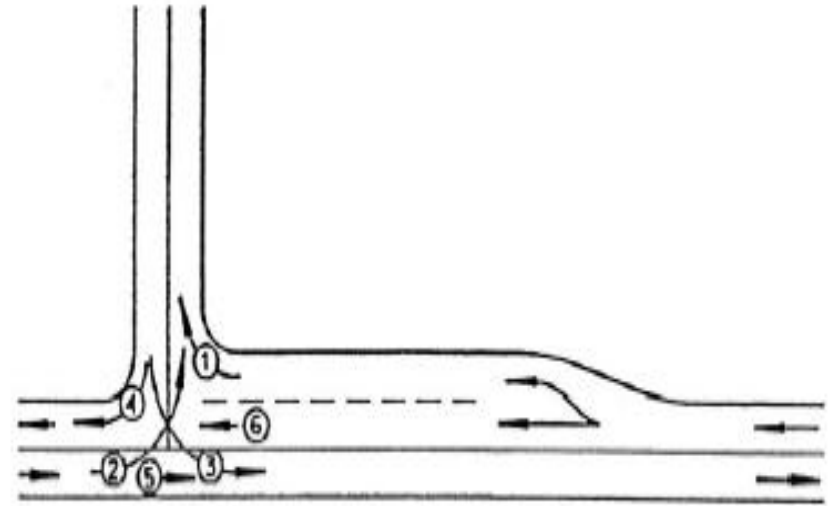
- Should facilitate driver's control of vehicle
- Avoid significant changes in grade
- Typically $\leq 3\%$
- Continue major street grade through intersection

- **Types and Examples of at grade intersections**

1- Three-leg/T intersections

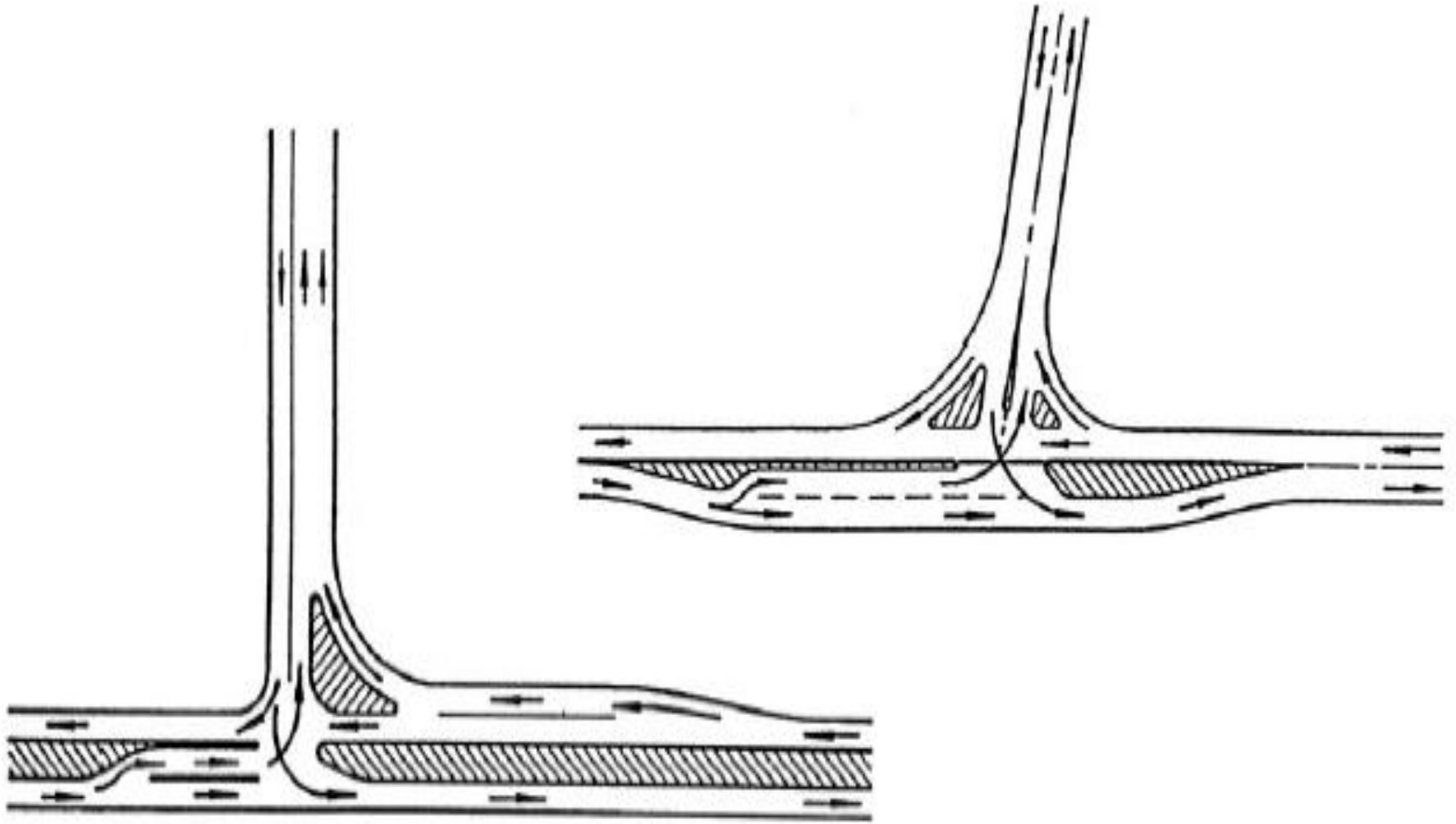


Plain T intersection

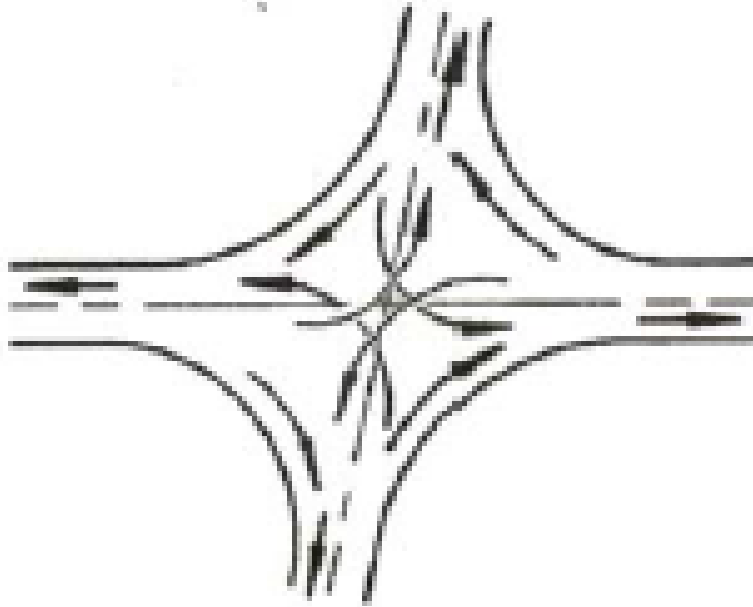


T intersection with right-turn lane

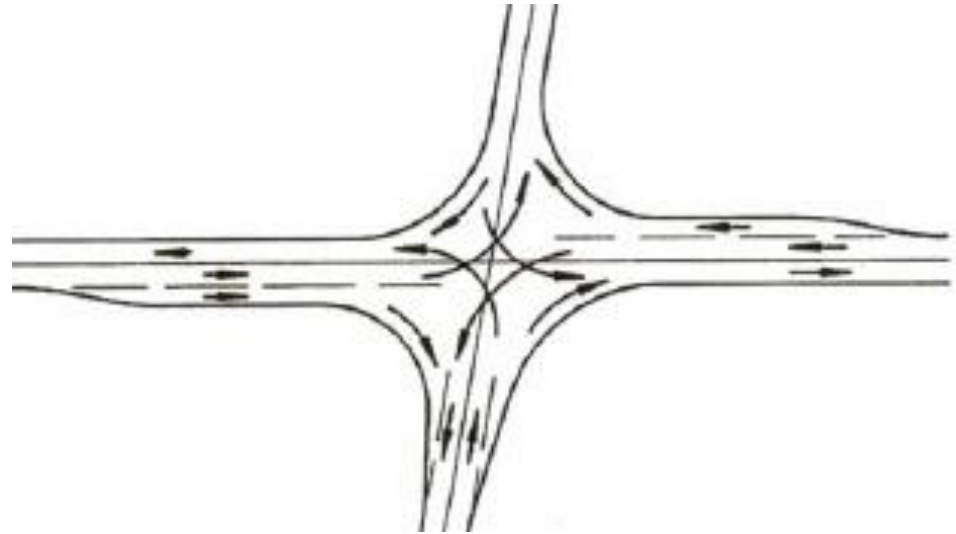
Channelized T intersection



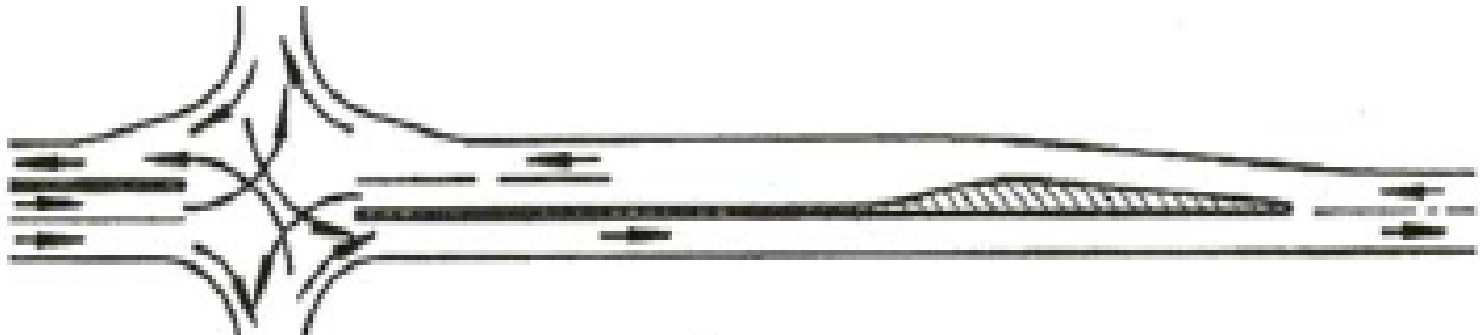
Four-leg Intersections



Plain

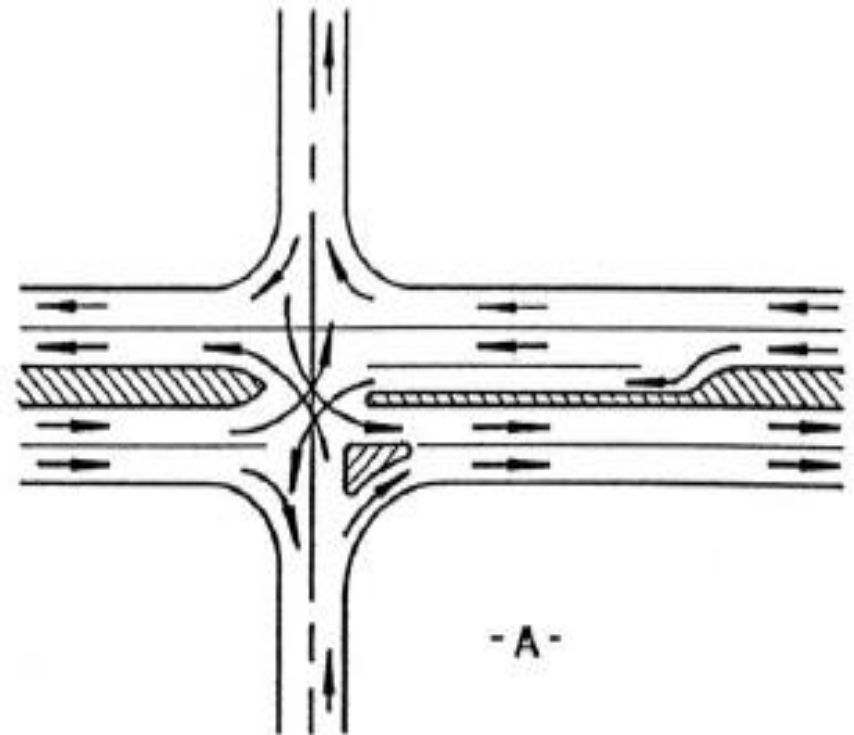
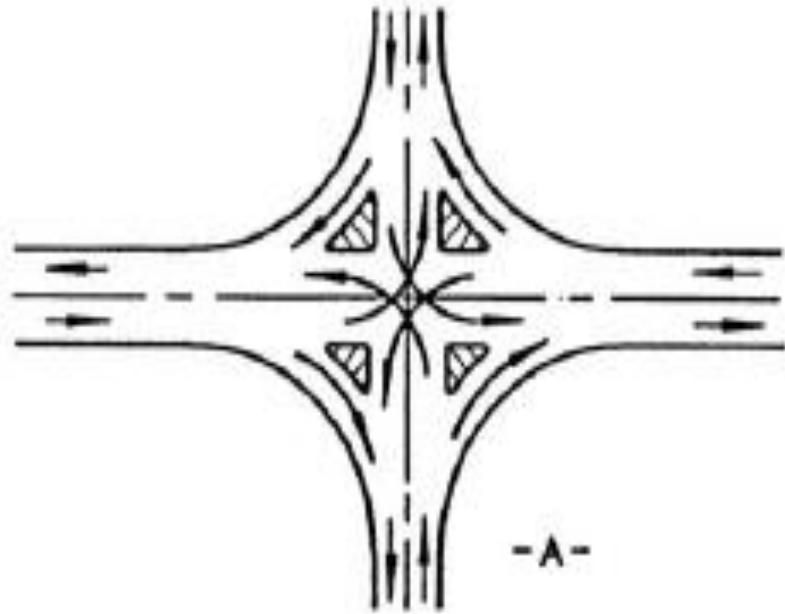


flared

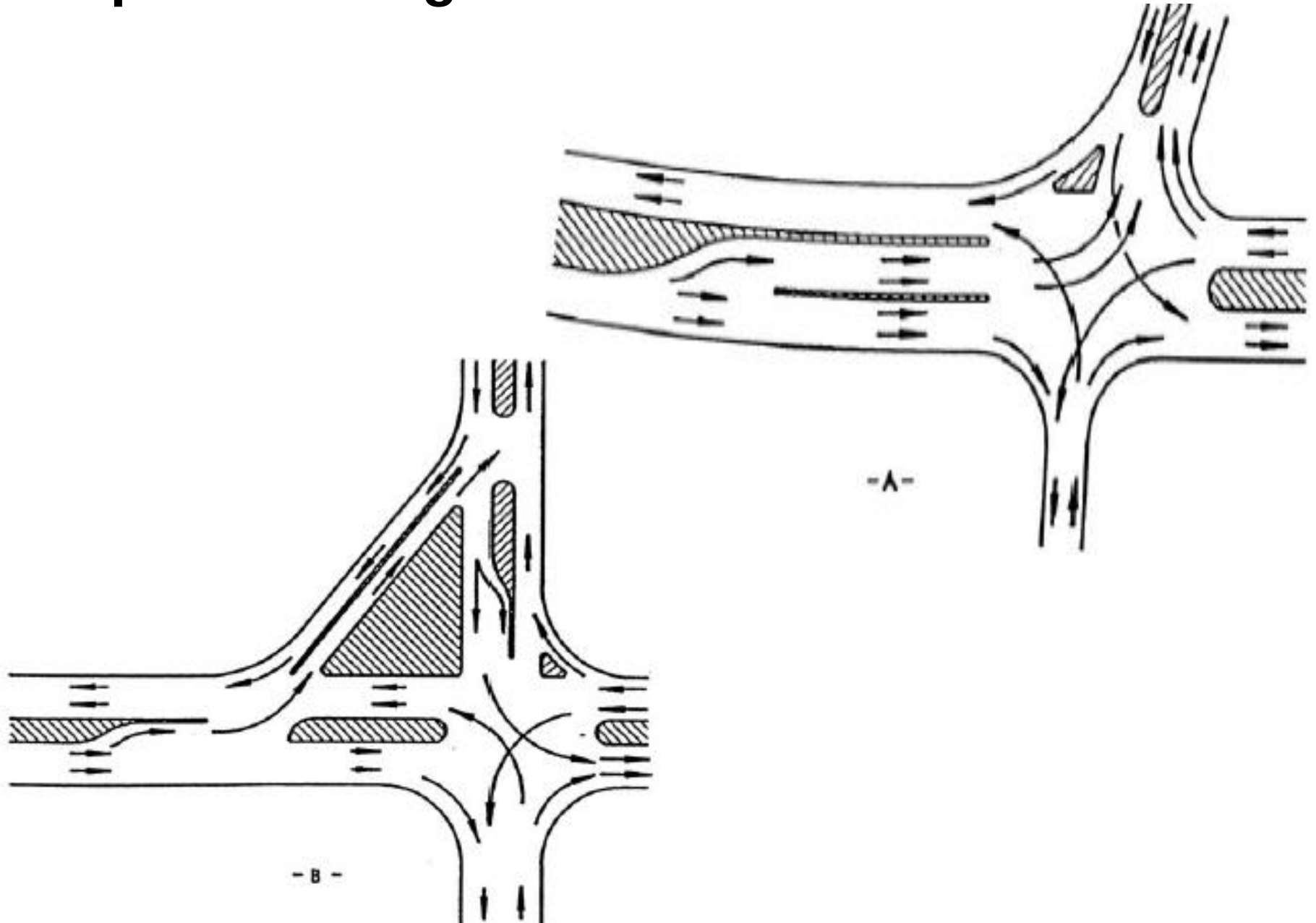


Flared and marked

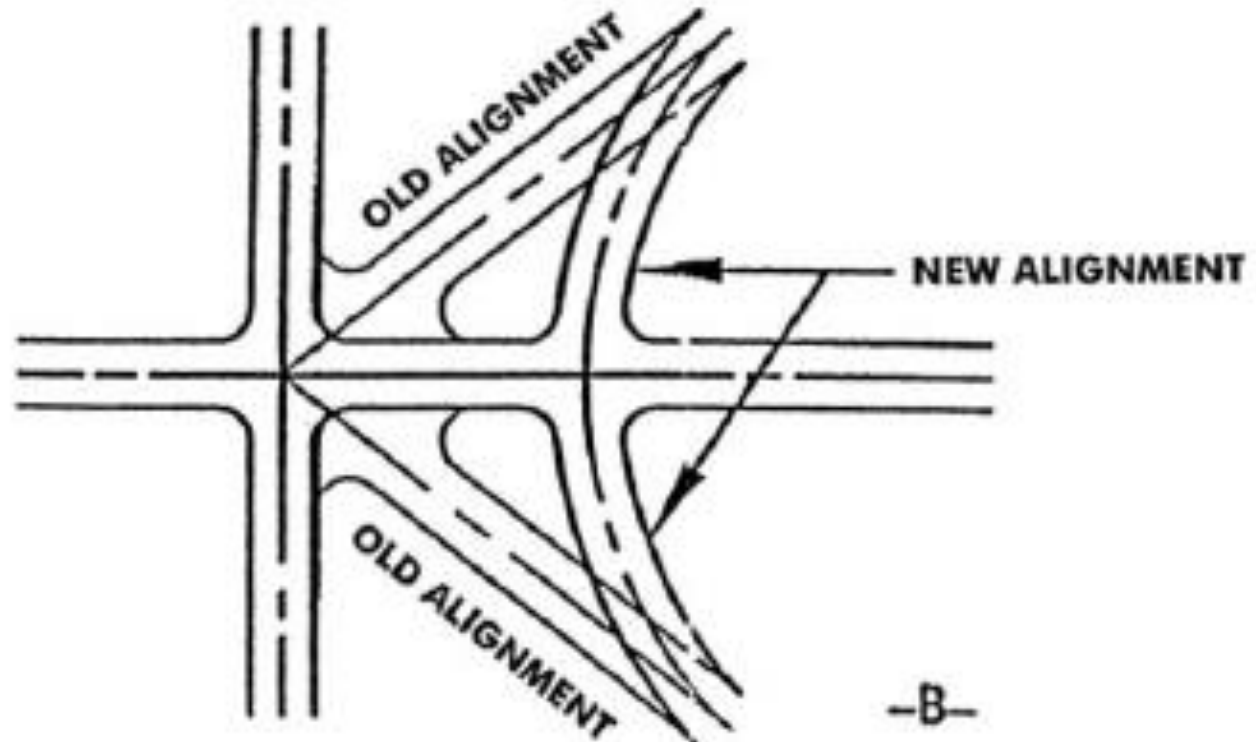
Channelized Four Leg



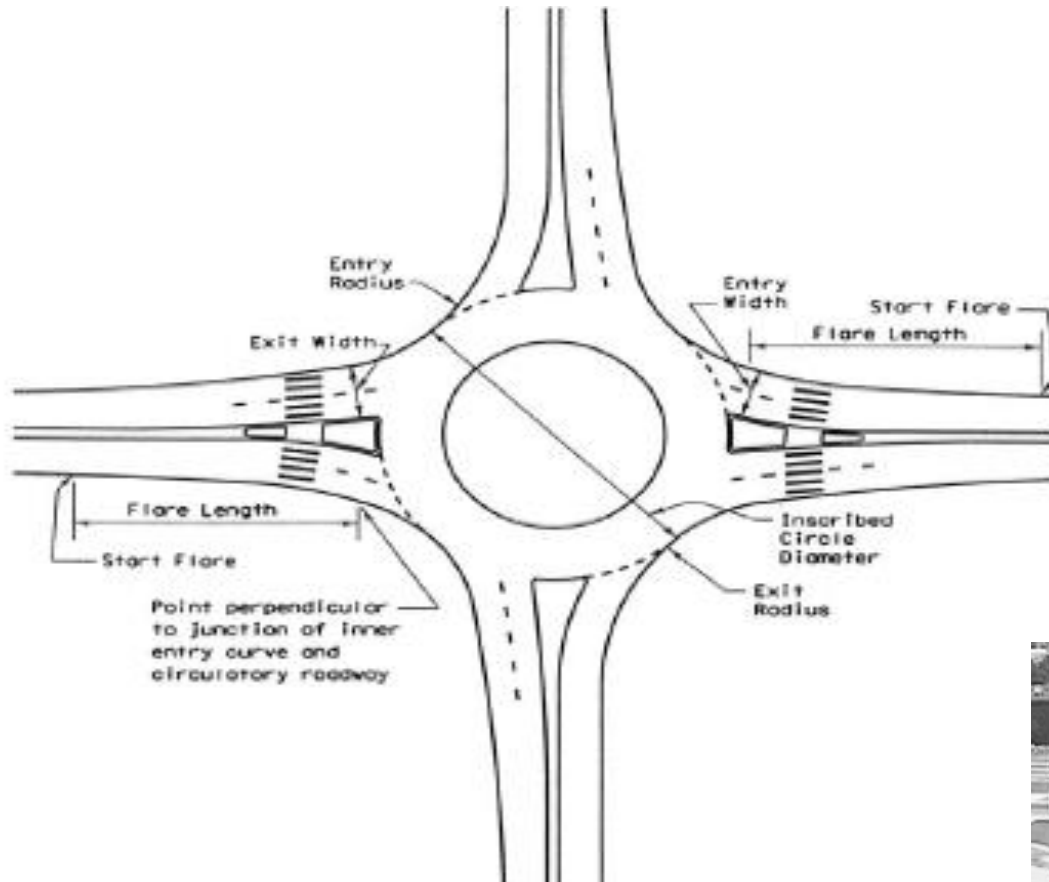
Complex four-leg:



Multi-leg Intersections & realigning



Roundabout



At-grade Intersection Design : Turning

- Minimum Edge-of-Traveled Way Design: *The width of turning roadways* for intersection are governed by :

1. *Traffic volume*

2. *Design vehicles*

1. P design vehicle (most urban area, parkway intersection etc.)
2. SU design vehicle (rural or wherever with high percentage of SU vehicle)
3. Semitrailer combination design vehicles (wherever with high presence of trucks)

Design Vehicles

Set of 20 design vehicles with standard physical dimensions according to AASHTO

P	=	passenger car	WB-65	=	interstate semi-trailer (wheelbase = 65 ft)
SU	=	single-unit truck	WB-67D	=	double trailer combination (wheelbase = 67 ft)
BUS-40	=	intercity bus with a 40-ft wheelbase	WB-100T	=	triple semi-trailer/trailers (wheelbase = 100 ft)
BUS-45	=	intercity bus with a 45-ft wheelbase	WB-109D	=	turnpike double semi-trailer/trailer (wheelbase = 109 ft)
CITY-BUS	=	transit bus	MH	=	motor home
S-BUS36	=	conventional school bus for 65 passengers	P/T	=	passenger car and camper
S-BUS40	=	large school bus for 84 passengers	P/B	=	passenger car and boat trailer
A-BUS	=	articulated bus	MH/B	=	motor home and boat trailer
WB-40	=	intermediate semi-trailer (wheelbase = 40 ft)	TR/W	=	farm tractor with one wagon
WB-50	=	intermediate semi-trailer (wheelbase = 50 ft)			
WB-62	=	interstate semi-trailer (wheelbase = 62 ft)			

The design of turning roadways means determination of :

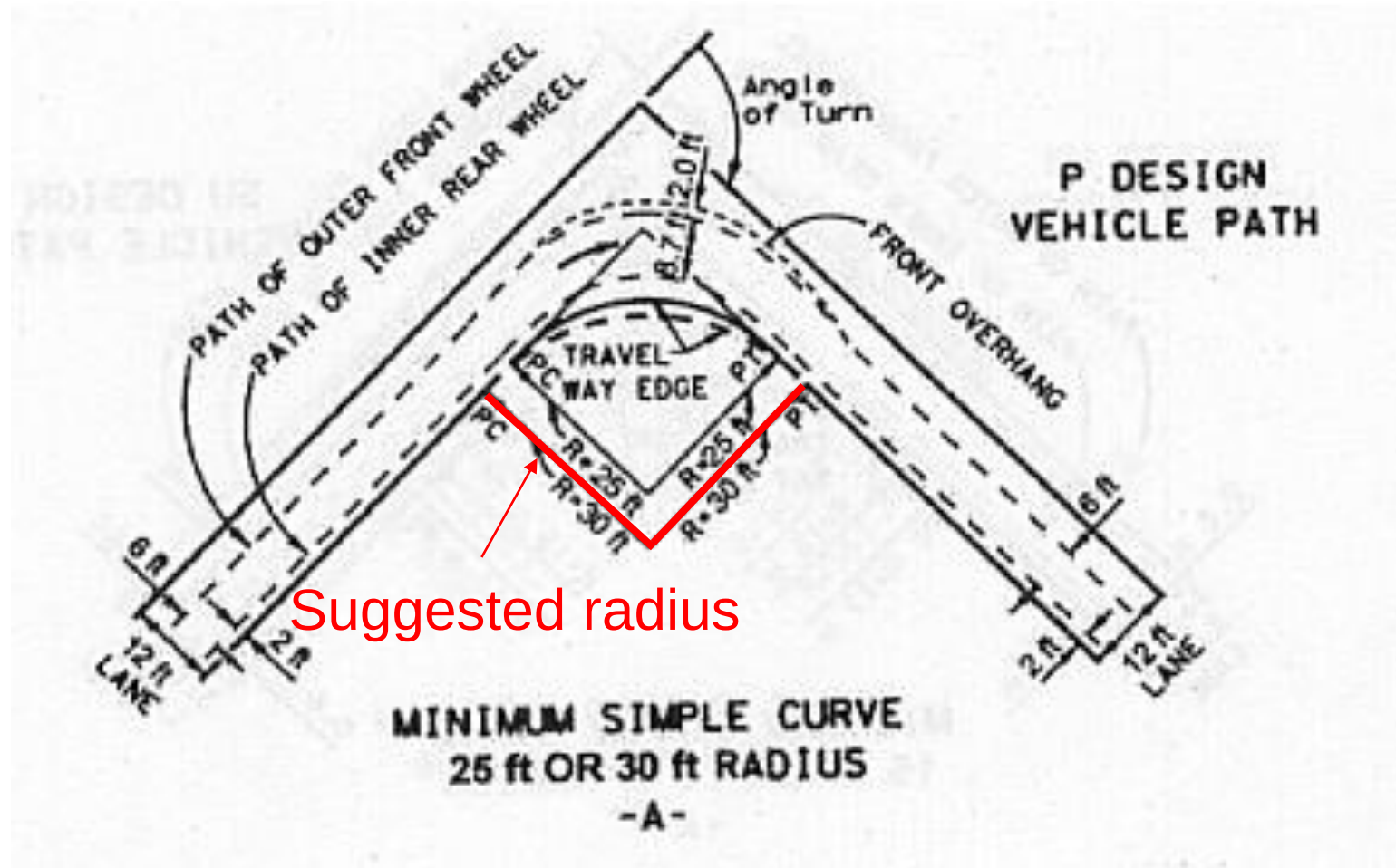
- 1. The width of pavements of turning roadways**
- 2. The min. radius of inner edge of pavement**

Regarding the min. Radius:

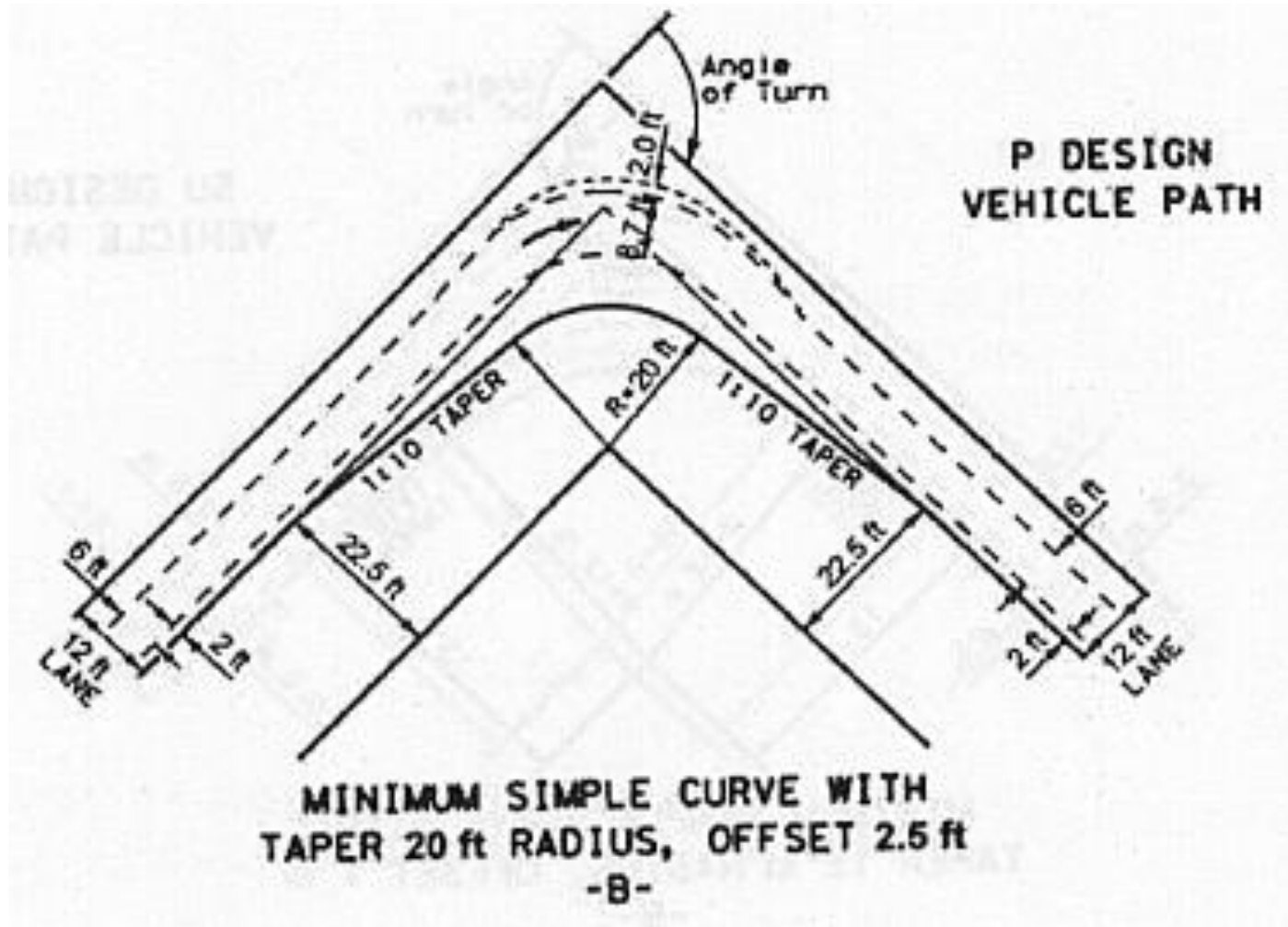
The edge-of-traveled way design may be:

- 1. Simple curve**
- 2. Simple curve with taper**
- 3. Three centered Compound curve (symmetric or asymmetric)**

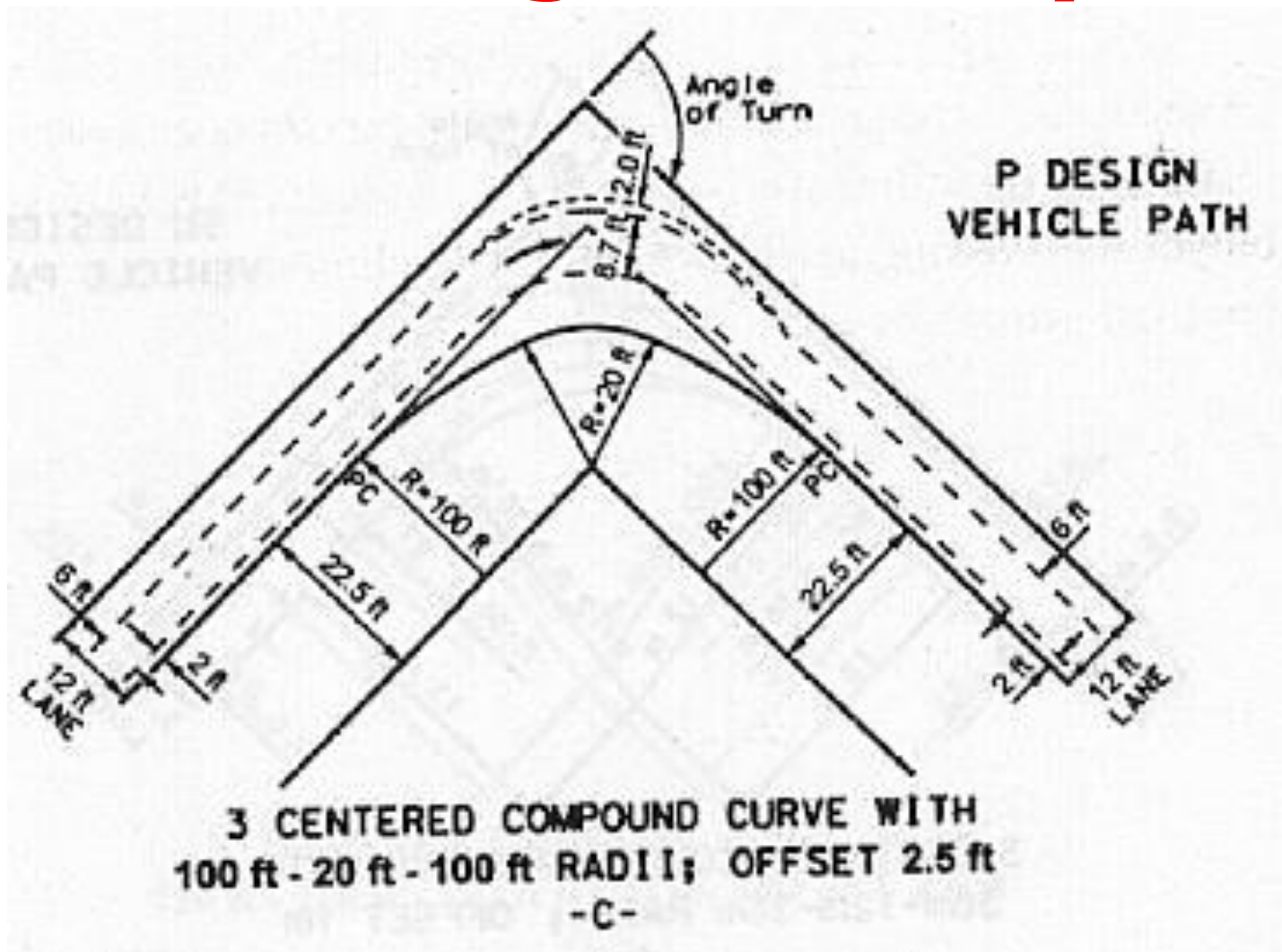
Turning Roadways



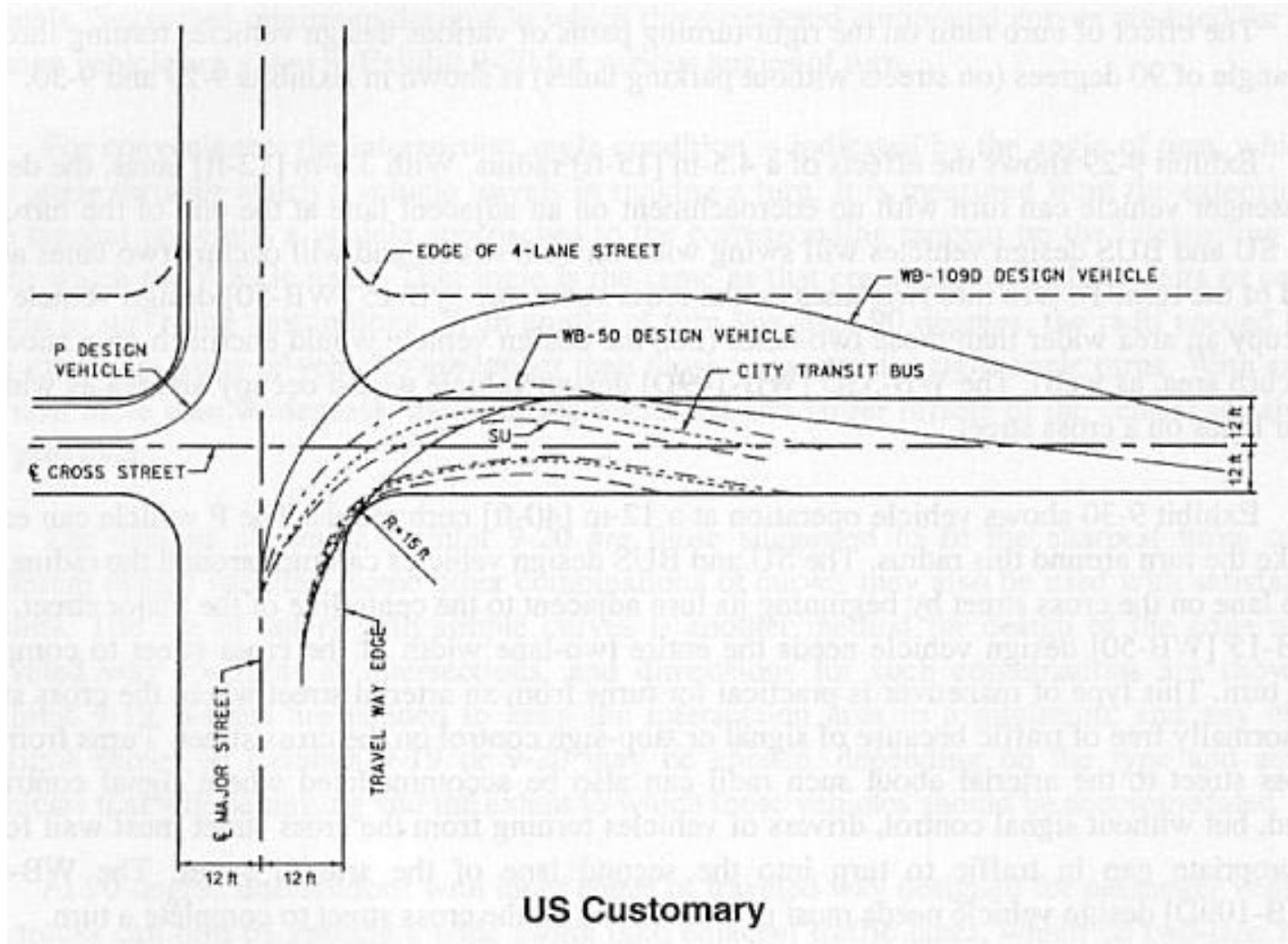
Turning Roadways



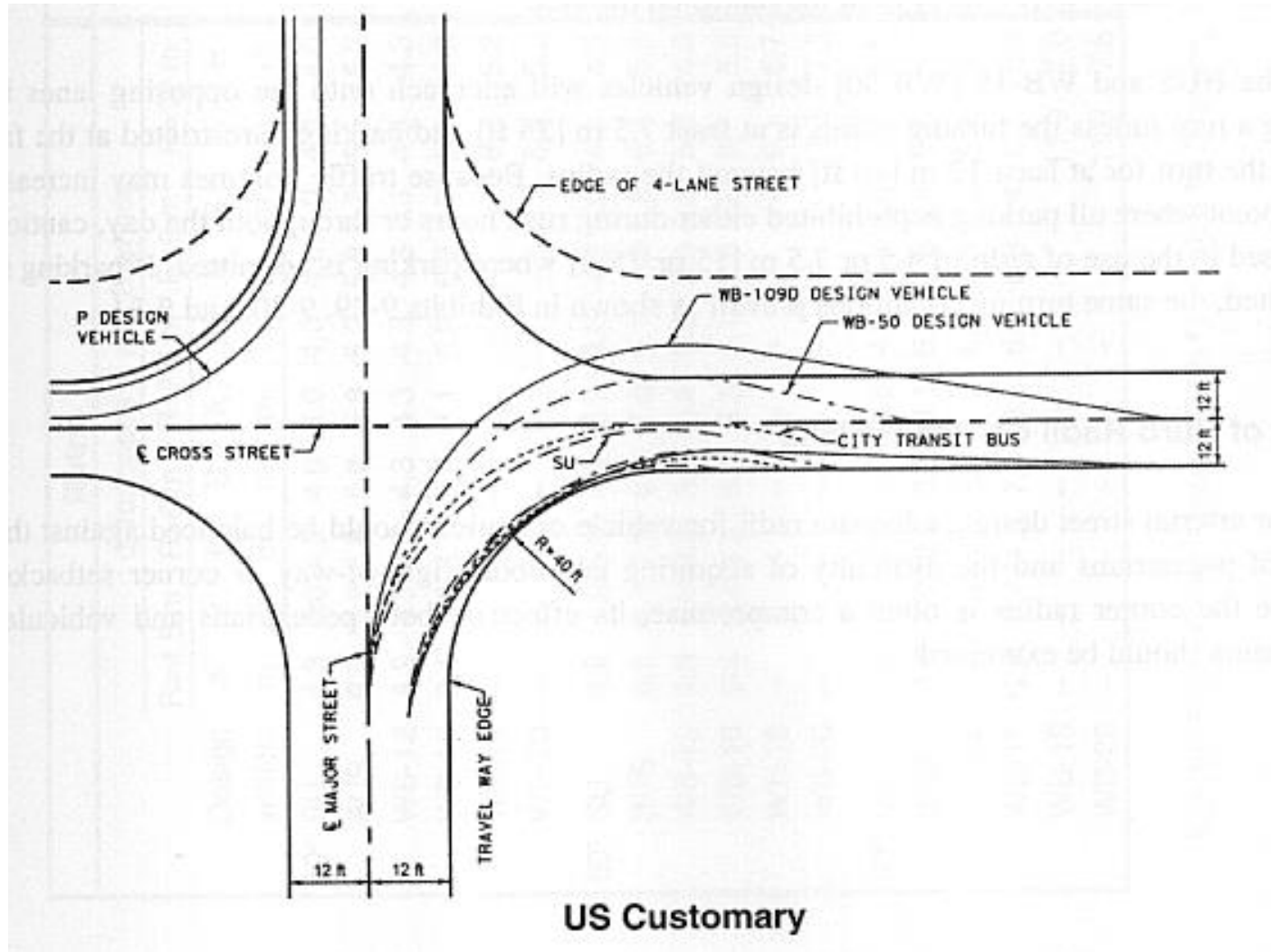
Turning Roadways



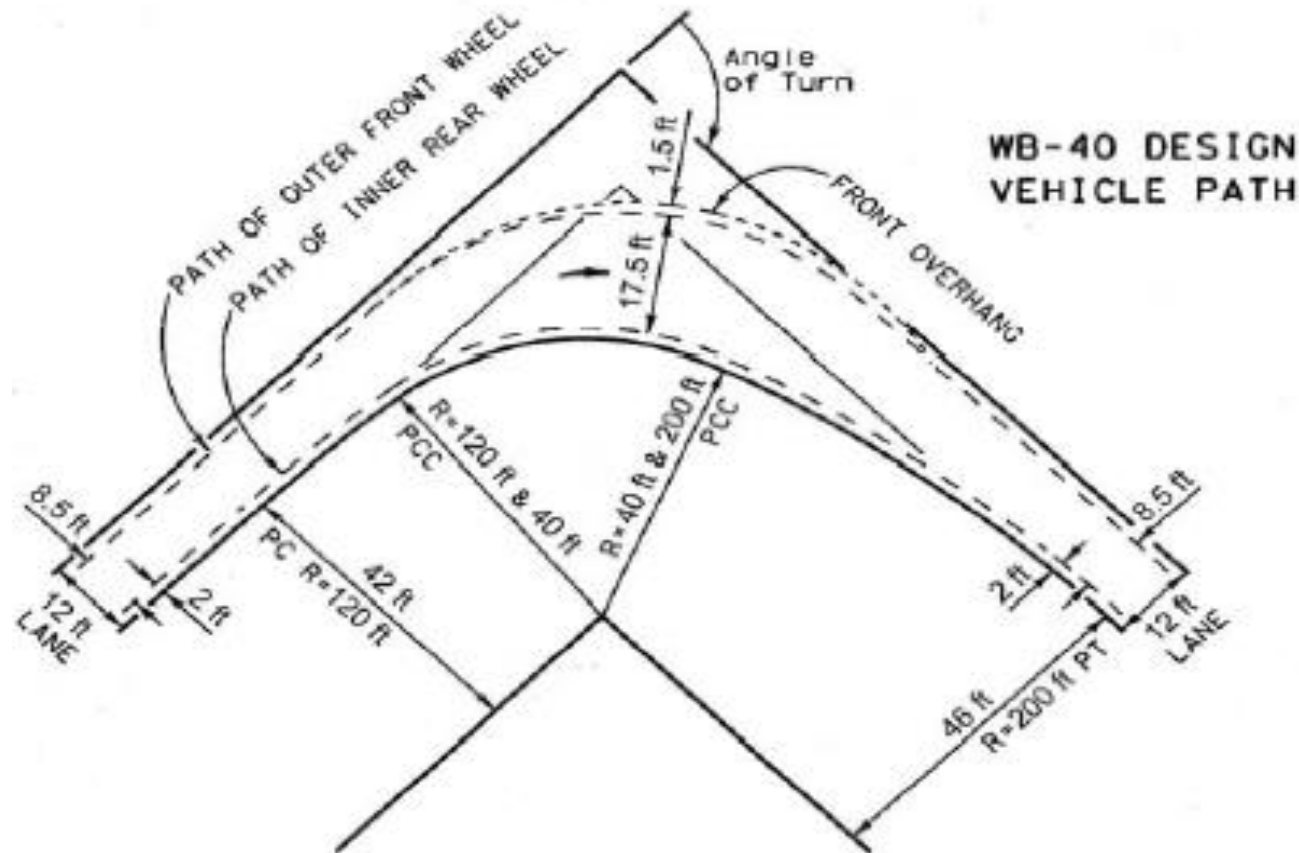
Turning Roadways



Turning Roadways



Example: Compound curve (WB-40 design vehicle)



3 CENTERED COMPOUND CURVE WITH
120 FT - 40 FT - 200 FT RADII; OFFSET 2 FT AND 6 FT
- A -

oblique-angle turns

Metric						US Customary					
Angle of turn (degrees)	Design vehicle	Simple curve radius (m)	Simple curve radius with taper			Angle of turn (degrees)	Design vehicle	Simple curve radius (ft)	Simple curve radius with taper		
			Radius (m)	Offset (m)	Taper L:T				Radius (ft)	Offset (ft)	Taper L:T
30	P	18	—	—	—	30	P	60	—	—	—
	SU	30	—	—	—		SU	100	—	—	—
	WB-12	45	—	—	—		WB-40	150	—	—	—
	WB-15	60	—	—	—		WB-50	200	—	—	—
	WB-19	110	67	1.0	15:1		WB-62	360	220	3.0	15:1
	WB-20	116	67	1.0	15:1		WB-67	380	220	3.0	15:1
	WB-30T	77	37	1.0	15:1		WB-100T	260	125	3.0	15:1
	WB-33D	145	77	1.1	20:1		WB-109D	475	260	3.5	20:1
45	P	15	—	—	—	45	P	50	—	—	—
	SU	23	—	—	—		SU	75	—	—	—
	WB-12	36	—	—	—		WB-40	120	—	—	—
	WB-15	53	36	0.6	15:1		WB-50	175	120	2.0	15:1
	WB-19	70	43	1.2	15:1		WB-62	230	145	4.0	15:1
	WB-20	76	43	1.3	15:1		WB-67	250	145	4.5	15:1
	WB-30T	60	35	0.8	15:1		WB-100T	200	115	2.5	15:1
	WB-33D	—	60	1.3	20:1		WB-109D	—	200	4.5	20:1
60	P	12	—	—	—	60	P	40	—	—	—
	SU	18	—	—	—		SU	60	—	—	—
	WB-12	28	—	—	—		WB-40	90	—	—	—
	WB-15	45	29	1.0	15:1		WB-50	150	120	3.0	15:1
	WB-19	50	43	1.2	15:1		WB-62	170	140	4.0	15:1
	WB-20	60	43	1.3	15:1		WB-67	200	140	4.5	15:1
	WB-30T	46	29	0.8	15:1		WB-100T	150	95	2.5	15:1
	WB-33D	—	54	1.3	20:1		WB-109D	—	180	4.5	20:1

Exhibit 9-19. Edge-of-Traveled-Way Designs for Turns at Intersections

Metric						US Customary					
Angle of turn (degrees)	Design vehicle	Simple curve radius (m)	Simple curve radius with taper			Angle of turn (degrees)	Design vehicle	Simple curve radius (ft)	Simple curve radius with taper		
			Radius (m)	Offset (m)	Taper L:T				Radius (ft)	Offset (ft)	Taper L:T
75	P	11	8	0.6	10:1	75	P	35	25	2.0	10:1
	SU	17	14	0.6	10:1		SU	55	45	2.0	10:1
	WB-12	—	18	0.6	15:1		WB-40	—	60	2.0	15:1
	WB-15	—	20	1.0	15:1		WB-50	—	65	3.0	15:1
	WB-19	—	43	1.2	20:1		WB-62	—	145	4.0	20:1
	WB-20	—	43	1.3	20:1		WB-67	—	145	4.5	20:1
	WB-30T	—	26	1.0	15:1		WB-100T	—	85	3.0	15:1
	WB-33D	—	42	1.7	20:1		WB-109D	—	140	5.5	20:1
90	P	9	6	0.8	10:1	90	P	30	20	2.5	10:1
	SU	15	12	0.6	10:1		SU	50	40	2.0	10:1
	WB-12	—	14	1.2	10:1		WB-40	—	45	4.0	10:1
	WB-15	—	18	1.2	15:1		WB-50	—	60	4.0	15:1
	WB-19	—	36	1.3	30:1		WB-62	—	120	4.5	30:1
	WB-20	—	37	1.3	30:1		WB-67	—	125	4.5	30:1
	WB-30T	—	25	0.8	15:1		WB-100T	—	85	2.5	15:1
	WB-33D	—	35	0.9	15:1		WB-109D	—	115	2.9	15:1
105	P	—	6	0.8	8:1	105	P	—	20	2.5	8:1
	SU	—	11	1.0	10:1		SU	—	35	3.0	10:1
	WB-12	—	12	1.2	10:1		WB-40	—	40	4.0	10:1
	WB-15	—	17	1.2	15:1		WB-50	—	55	4.0	15:1
	WB-19	—	35	1.0	15:1		WB-62	—	115	3.0	15:1
	WB-20	—	35	1.0	15:1		WB-67	—	115	3.0	15:1
	WB-30T	—	22	1.0	15:1		WB-100T	—	75	3.0	15:1
	WB-33D	—	28	2.8	20:1		WB-109D	—	90	9.2	20:1

Metric						US Customary					
Angle of turn (degrees)	Design vehicle	Simple curve radius (m)	Simple curve radius with taper			Angle of turn (degrees)	Design vehicle	Simple curve radius (ft)	Simple curve radius with taper		
			Radius (m)	Offset (m)	Taper L:T				Radius (ft)	Offset (ft)	Taper L:T
120	P	—	6	0.6	10:1	120	P	—	20	2.0	10:1
	SU	—	9	1.0	10:1		SU	—	30	3.0	10:1
	WB-12	—	11	1.5	8:1		WB-40	—	35	5.0	8:1
	WB-15	—	14	1.2	15:1		WB-50	—	45	4.0	15:1
	WB-19	—	30	1.5	15:1		WB-62	—	100	5.0	15:1
	WB-20	—	31	1.6	15:1		WB-67	—	105	5.2	15:1
	WB-30T	—	20	1.1	15:1		WB-100T	—	65	3.5	15:1
	WB-33D	—	26	2.8	20:1		WB-109D	—	85	9.2	20:1
135	P	—	6	0.5	10:1	135	P	—	20	1.5	10:1
	SU	—	9	1.2	10:1		SU	—	30	4.0	10:1
	WB-12	—	9	2.5	15:1		WB-40	—	30	8.0	15:1
	WB-15	—	12	2.0	15:1		WB-50	—	40	6.0	15:1
	WB-19	—	24	1.5	20:1		WB-62	—	80	5.0	20:1
	WB-20	—	25	1.6	20:1		WB-67	—	85	5.2	20:1
	WB-30T	—	19	1.7	15:1		WB-100T	—	65	5.5	15:1
	WB-33D	—	25	2.6	20:1		WB-109D	—	85	8.5	20:1
150	P	—	6	0.6	10:1	150	P	—	18	2.0	10:1
	SU	—	9	1.2	8:1		SU	—	30	4.0	8:1
	WB-12	—	9	2.0	8:1		WB-40	—	30	6.0	8:1
	WB-15	—	11	2.1	6:1		WB-50	—	35	7.0	6:1
	WB-19	—	18	3.0	10:1		WB-62	—	60	10.0	10:1
	WB-20	—	19	3.1	10:1		WB-67	—	65	10.2	10:1
	WB-30T	—	19	2.2	10:1		WB-100T	—	65	7.3	10:1
	WB-33D	—	20	4.6	10:1		WB-109D	—	65	15.1	10:1

Turning roadway with corner Island

(later will be explained in details)

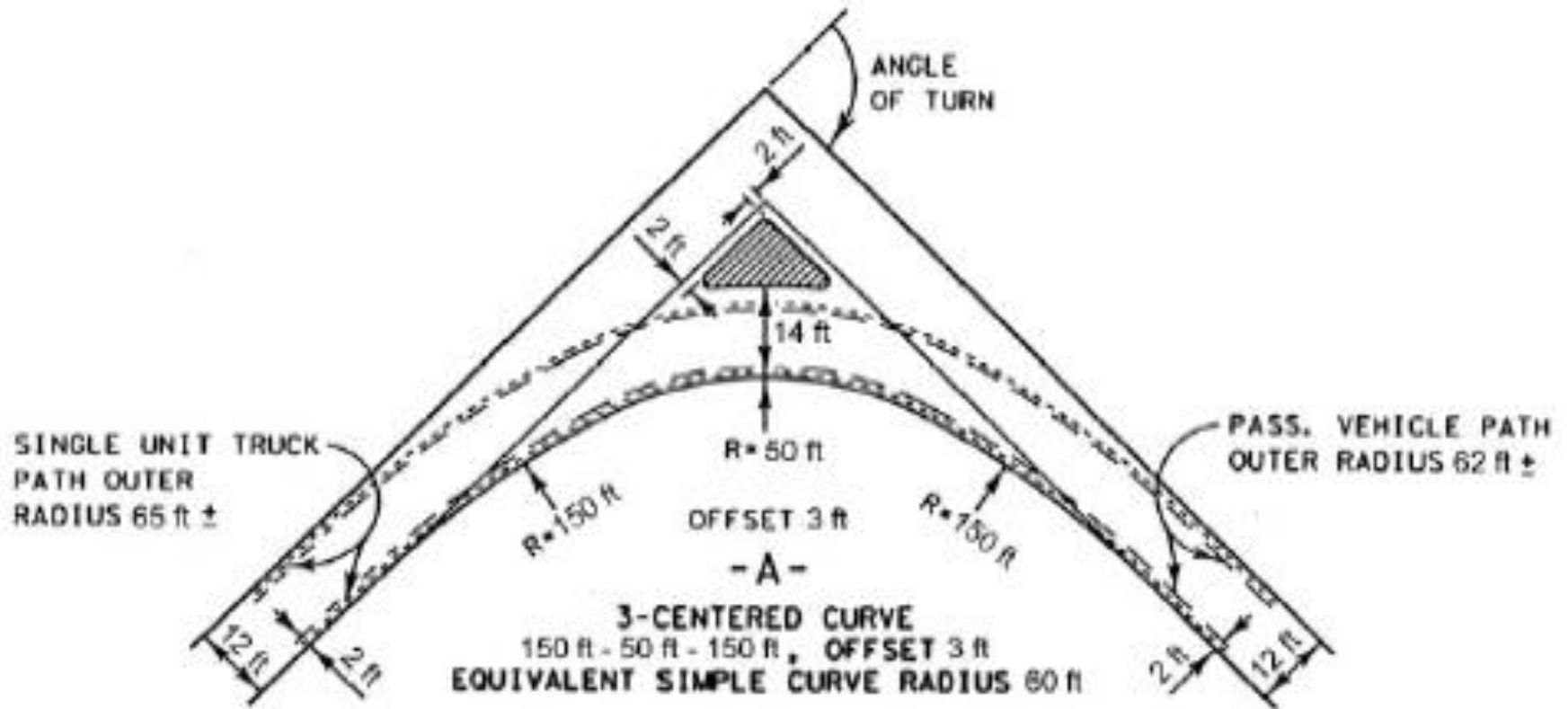


Exhibit 9-41. Minimum Turning Roadway Designs with Corner Islands
at Urban Locations (Continued)

High Speed Turns

US Customary								
Design (turning) speed, V (mph)	10	15	20	25	30	35	40	45
Side friction factor, f	0.38	0.32	0.27	0.23	0.20	0.18	0.16	0.15
Assumed minimum superelevation, e/100	0.00	0.00	0.02	0.04	0.06	0.08	0.09	0.10
Total e/100 + f	0.38	0.32	0.29	0.27	0.26	0.26	0.25	0.25
Calculated minimum radius, R (ft)	18	47	92	154	231	314	426	540
Suggested minimum radius curve for design (ft)	25	50	90	150	230	310	430	540
Average running speed (mph)	10	14	18	22	26	30	34	36

Turning speed $\leq$ 40 mph & intersection angle = 90 degree

Exhibit 3-43. Minimum Radii for Intersection Curves

Channelization

- Separates conflicting movements into definite paths of travel
- Uses pavement markings or traffic islands
- Directs vehicle paths so no more than 2 paths cross at one point
- Controls merging, diverging, and crossing angle of vehicles
- Gives priority to dominant movements.
- Provides storage area for turning vehicles
- Controls prohibited turns
- Restricts speed

Types of Channelization

- Raised islands
 - Urban
 - Provides refuge for pedestrians
 - $\leq 50 \text{ ft}^2$ in urban areas
 - $\leq 75 \text{ ft}^2$ in rural areas
- Pavement markings
 - Low pedestrian volume, low approach speeds



Types of Channelization

- Pavement edge
 - Rural – painted if high speed
 - Formed by diverging through and right turn lanes



Delineation With Pavement Marking

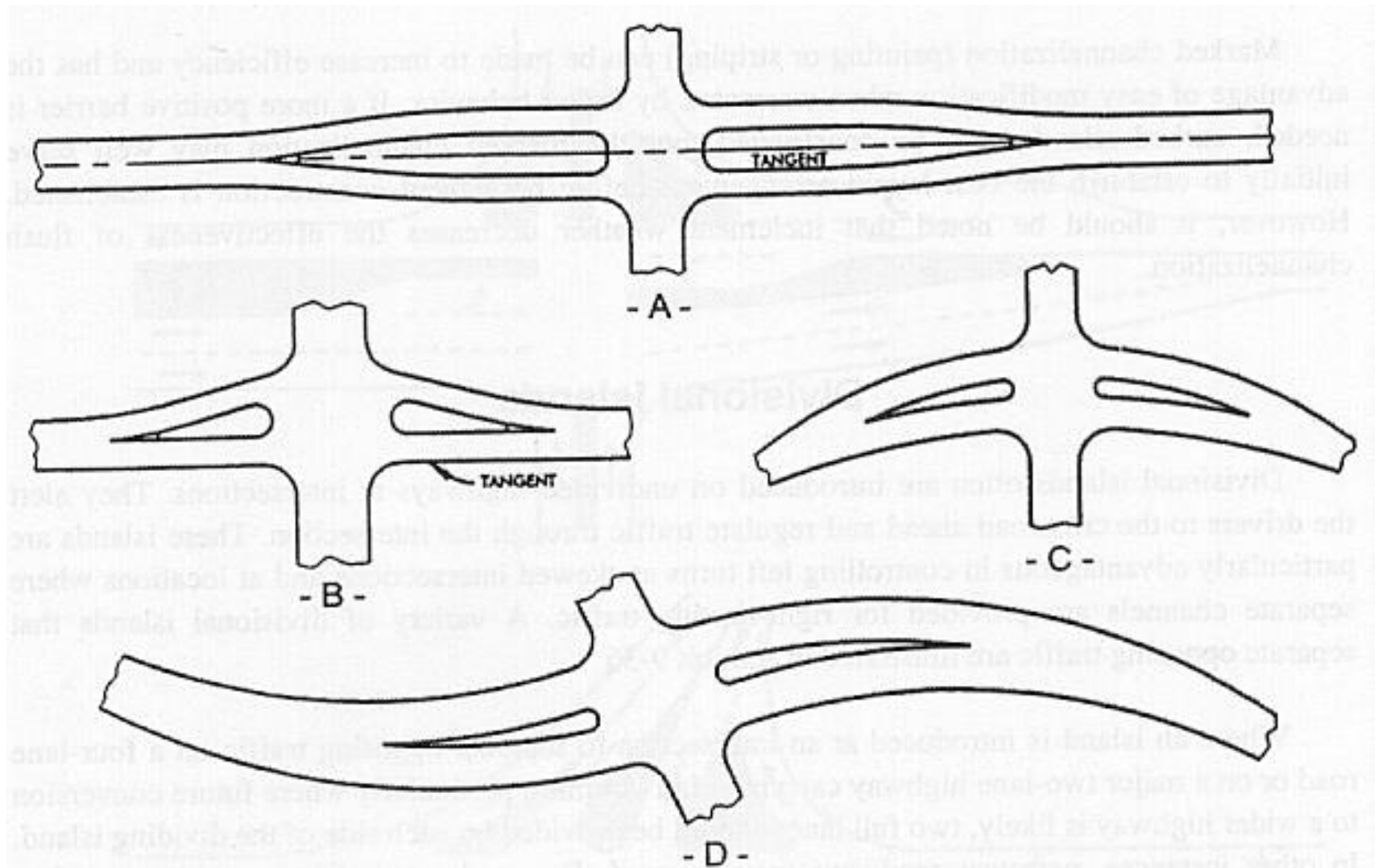


Islands

Area between traffic lanes used for controlling vehicle movements

- Channelizing Islands
 - Use to control and direct movement traffic at intersections
 - The path should be obvious to the driver
 - Avoid the use of multiple islands (three or more) to channelize various movements
 - Need to include pavement marking/delineation near the island
- Divisional islands
 - Use to control left turns and provide refuge for pedestrians at intersections
 - Usually built on 4-lane highways (2-lane with future expansion)
 - May use taper design

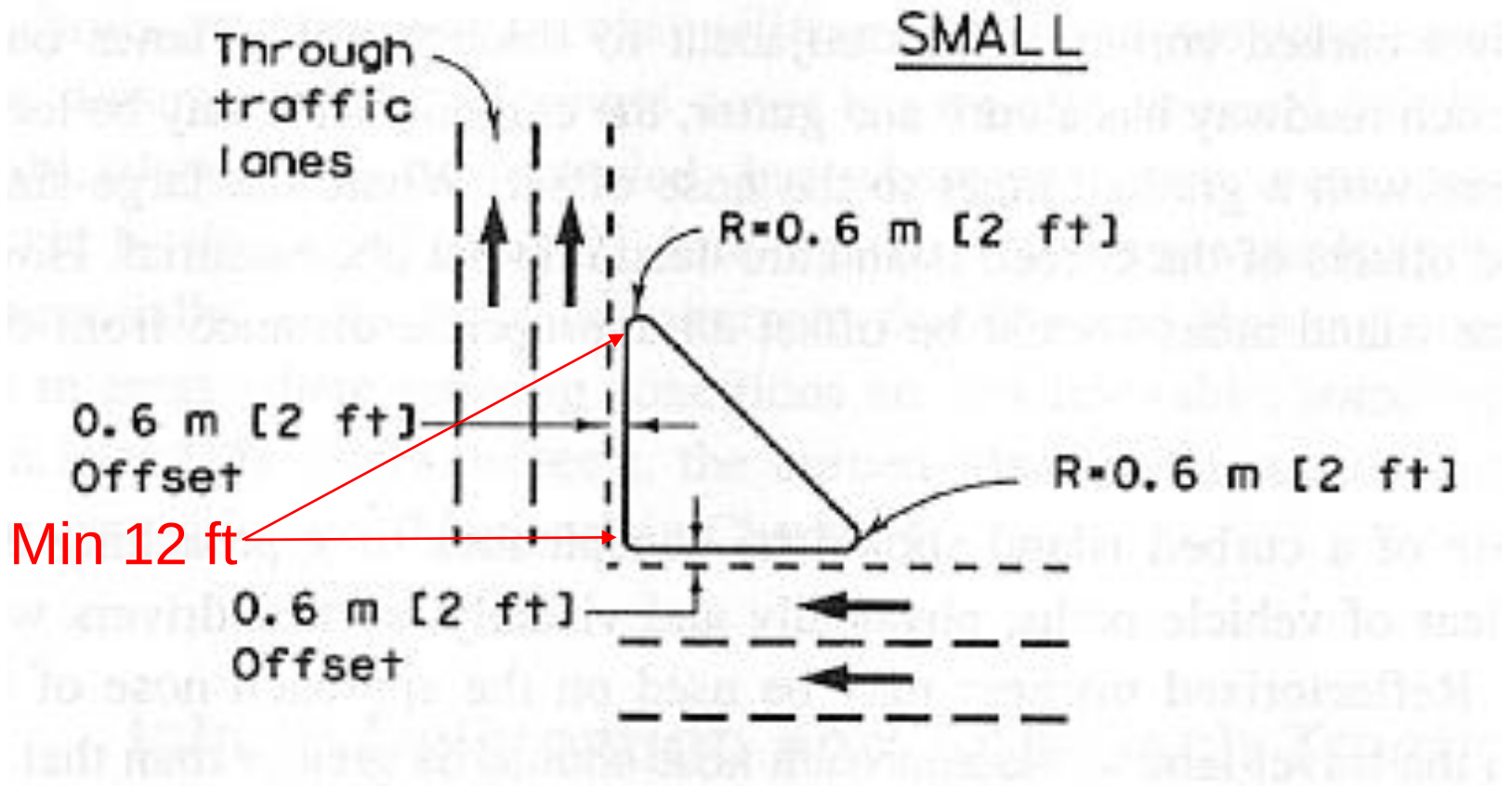
Islands



Islands

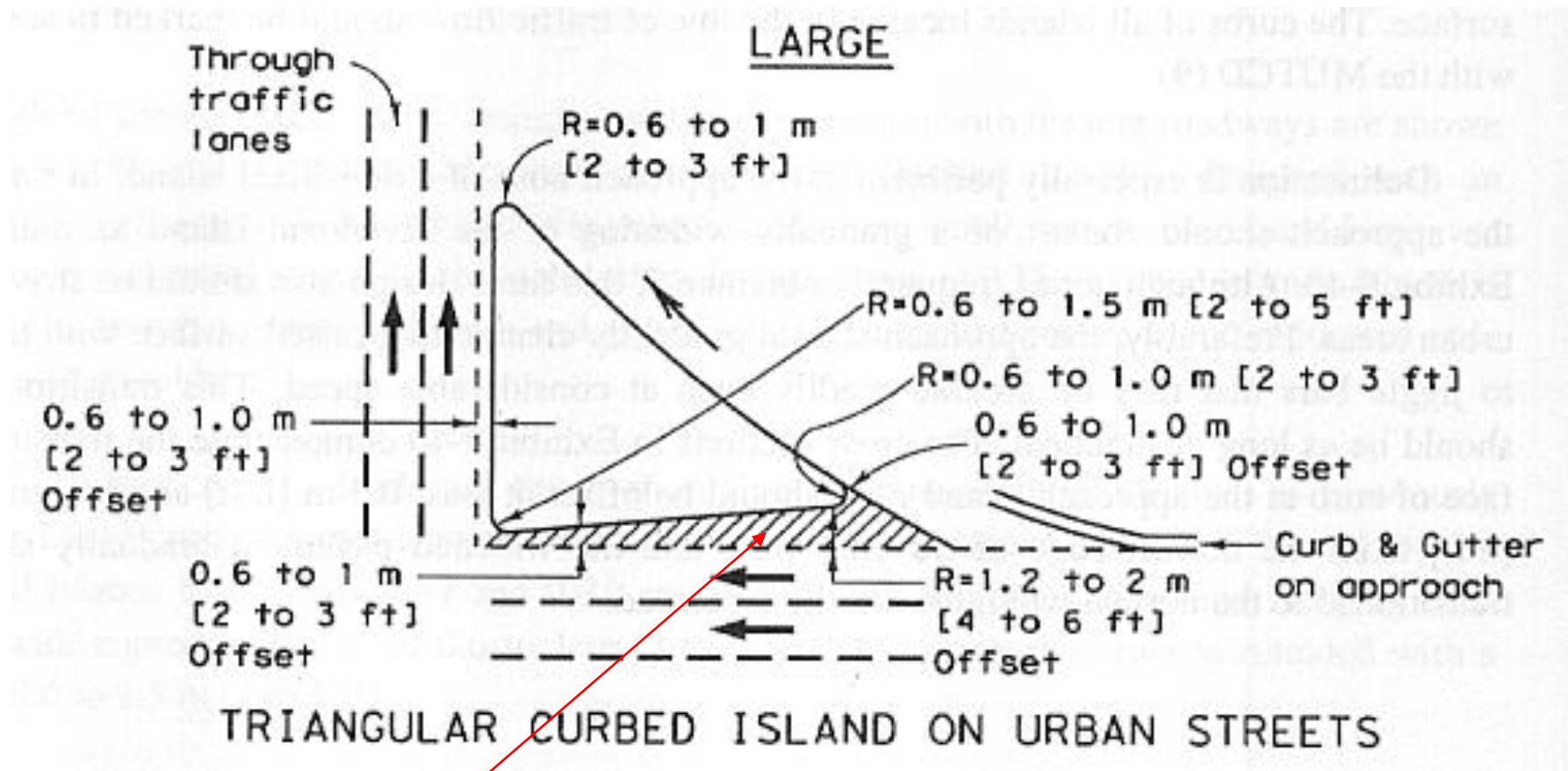
- Island Size and Designation
 - Corner islands
 - Urban: 50 ft²
 - Rural: 75 ft²
 - Length: minimum 12 ft for each side
 - Divisional islands
 - Width: 4 ft (6 ft if designed for pedestrians)
 - Length: 20 to 25 ft (high speed: 100 ft)
- Delineation
 - Curb height: 6 in (low speed)
 - May provide vegetation cover, mounted earth, shrubs for large islands
 - Corner island: offset and corner radii dependent on side length

Islands



Islands

LARGE

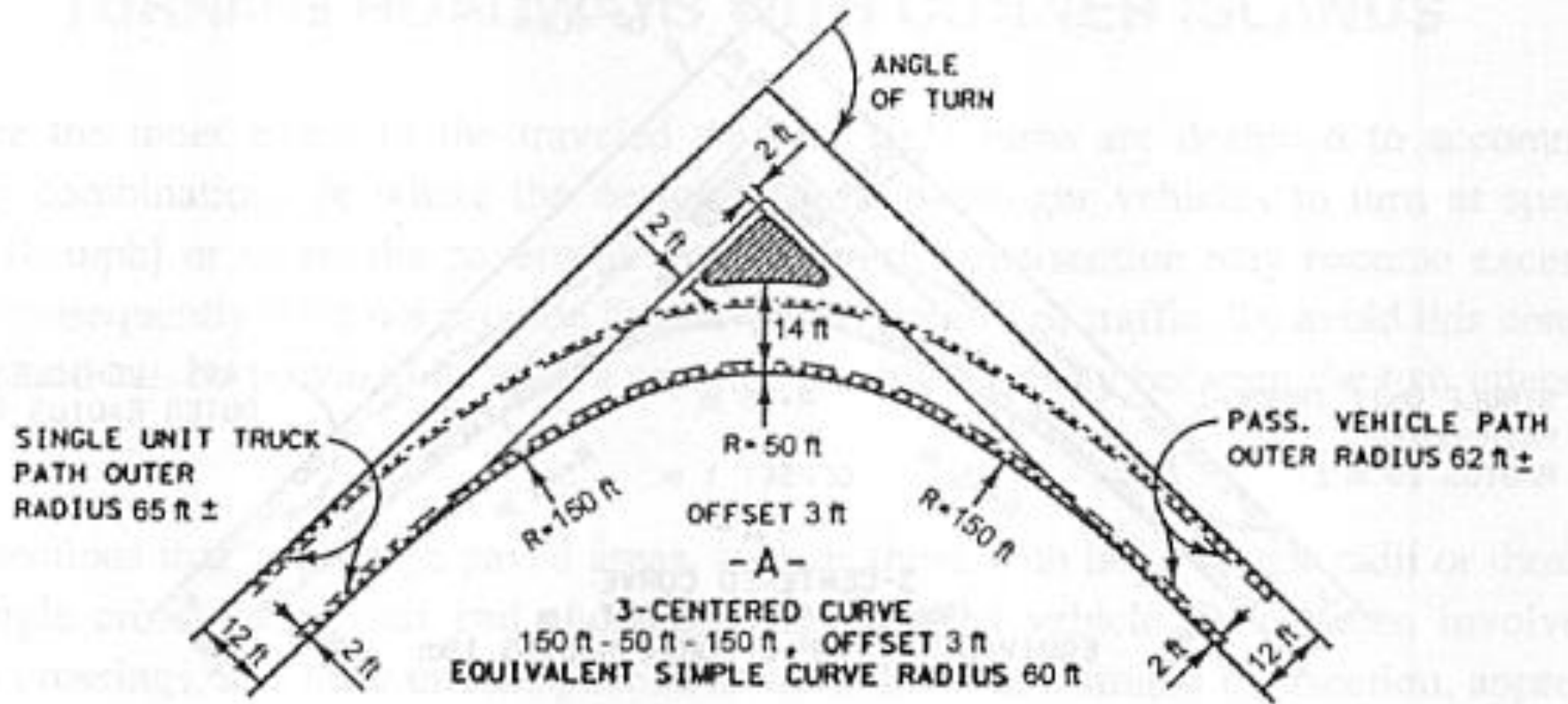


Painted stripes

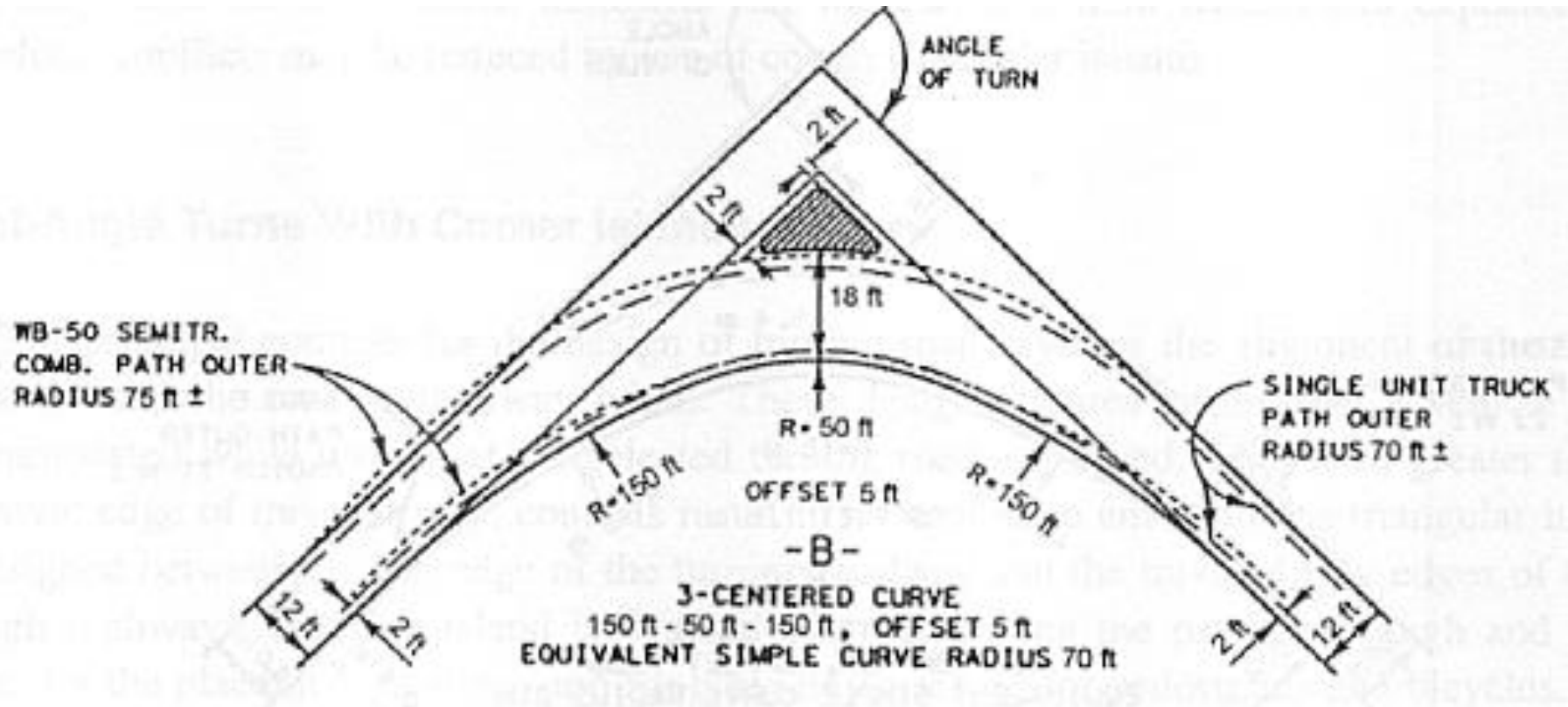
Islands

- Corner islands
 - The turning roadway should be provided with at least the minimum size island and the minimum width of roadway
 - Minimum offset: 2 ft
 - To discourage passenger cars from using a wide roadway, the roadway may be marked with paint or thermoplastic markings

Islands

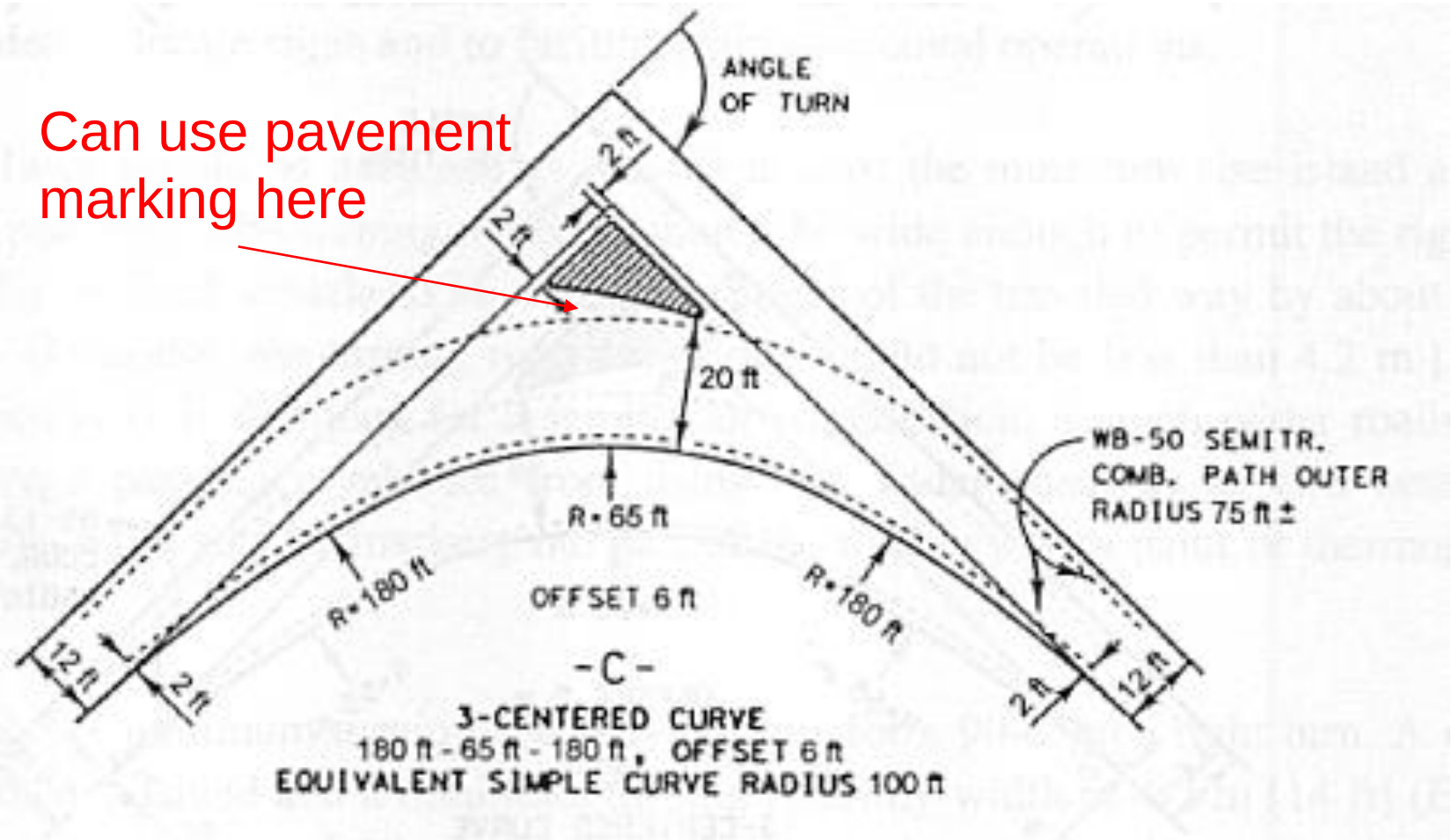


Islands



Islands

Can use pavement marking here



Islands

US Customary					
Angle of turn (degrees)	Design classification	Three-centered compound curve		Width of lane (ft)	Approx. island size (ft ²)
		Radii (ft)	Offset (ft)		
75	A	150-75-150	3.5	14	60
	B	150-75-150	5.0	18	50
	C	180-90-180	3.5	20	50
90 ^a	A	150-50-150	3.0	14	50
	B	150-50-150	5.0	18	80
	C	180-65-180	6.0	20	125
105	A	120-40-120	2.0	15	70
	B	100-35-100	5.0	22	50
	C	180-45-180	8.0	30	60
120	A	100-30-100	2.5	16	120
	B	100-30-100	5.0	24	90
	C	180-40-180	8.5	34	220
135	A	100-30-100	2.5	16	460
	B	100-30-100	5.0	26	370
	C	160-35-160	9.0	35	640
150	A	100-30-100	2.5	16	1400
	B	100-30-100	6.0	30	1170
	C	160-35-160	7.1	38	1720

A: Passenger cars + occasional single-unit truck

B: SU trucks + occasional semi-trailers (WB-50) (slight encroachment)

C: Full access to WB-50

Speed Change Lanes

- A Speed change lane is an auxiliary Lane including tapered areas primarily for the acceleration or deceleration of vehicles entering or leaving the through traffic lanes

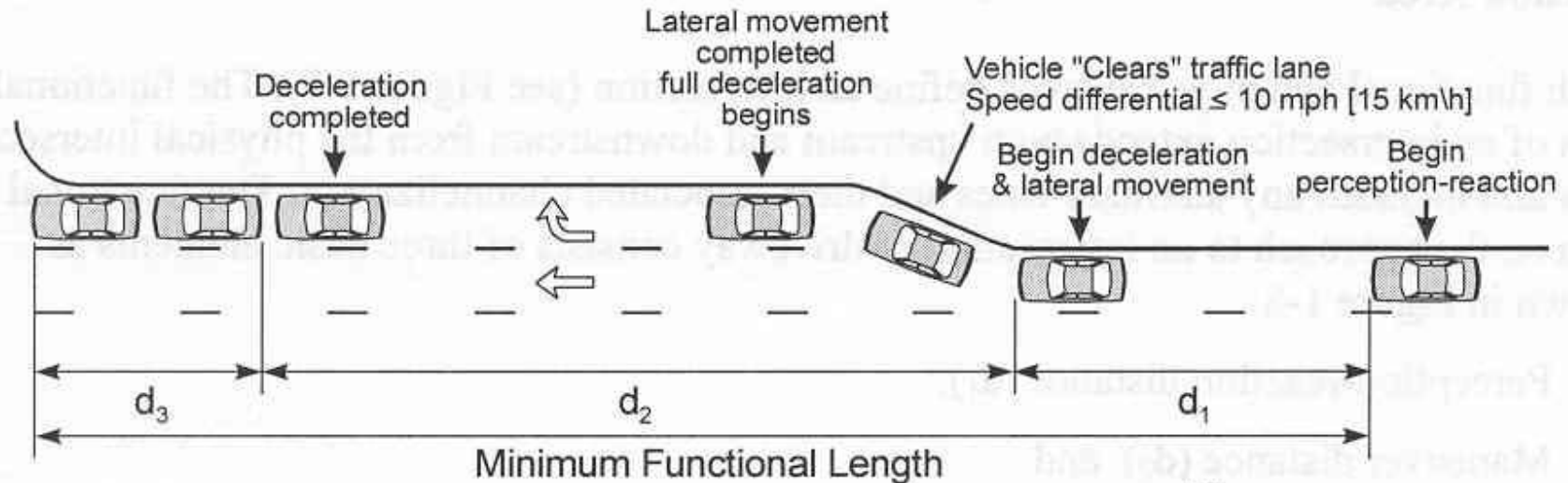


Figure 1-8. Elements of the Functional Area of an Intersection.¹⁷

Speed Change Lanes

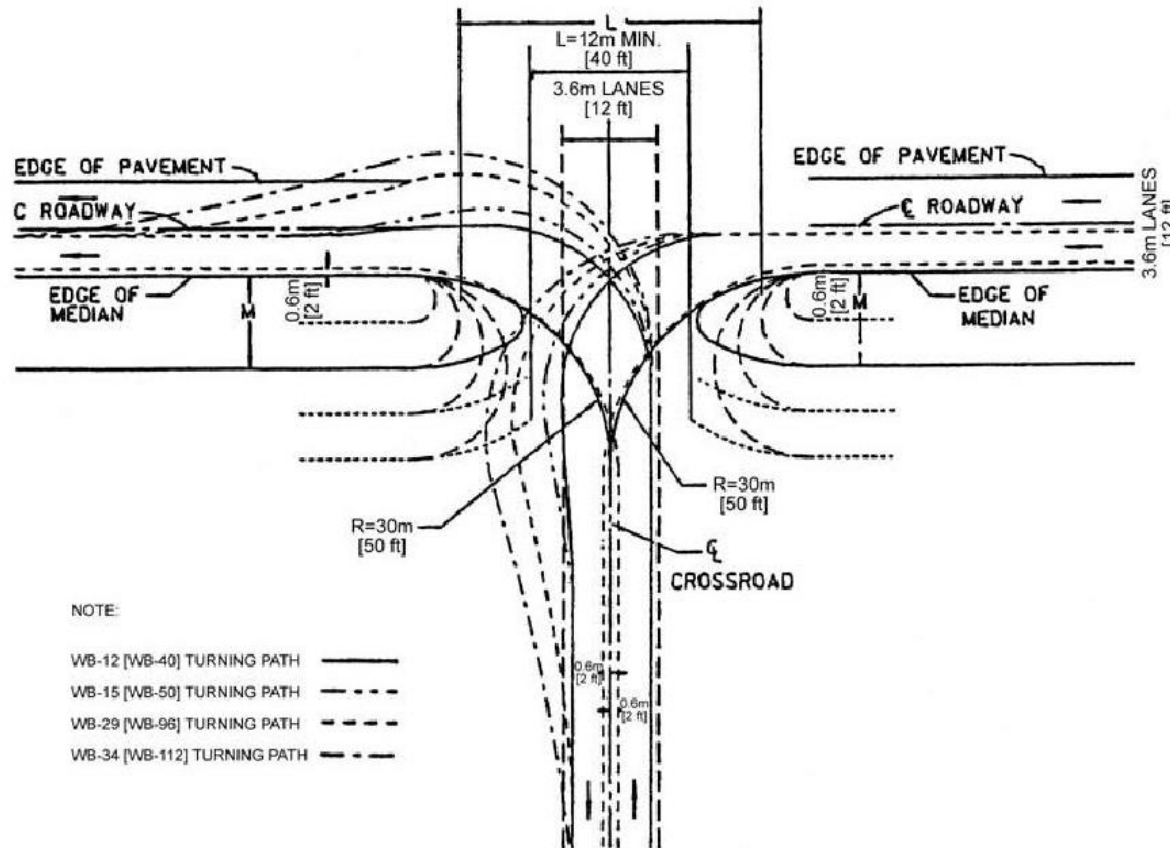
Left & Right Turn Lanes Design

- Number of likely queued vehicles
- Type of control
- Number of turning vehicles
- Length of vehicles

Deceleration Lanes

- Provides distance for turning vehicles to decelerate away without interfering with through traffic
- Deceleration lane length depends on:
 - Speed
 - number of queued vehicles
 - vehicle length

Median Openings



Metric			US Customary		
M Width of median (m)	L = Minimum length of median opening (m)		M Width of median (ft)	L = Minimum length of median opening (ft)	
	Semicircular	Bullet nose		Semicircular	Bullet nose
1.2	43.8	36.6	4	146	122
1.8	43.2	34.5	6	144	115
2.4	42.6	33.0	8	142	110
3.0	42.0	31.5	10	140	105
3.6	41.4	30.0	12	138	100
4.2	40.8	28.8	14	136	96
4.8	40.2	27.6	16	134	92
6.0	39.0	25.5	20	130	85
7.2	37.8	23.4	24	126	78
8.4	36.6	21.9	28	122	73
9.6	35.4	20.1	32	118	67
10.8	34.2	18.6	36	114	62
12.0	30.0	17.1	40	100	57
18.0	27.0	12.0 min	60	90	40 min
24.0	21.0	12.0 min	80	70	40 min
30.0	15.0	12.0 min	100	50	40 min
33.0	12.0 min	12.0 min	110	40 min	40 min
36.0	12.0 min	12.0 min	120	40 min	40 min

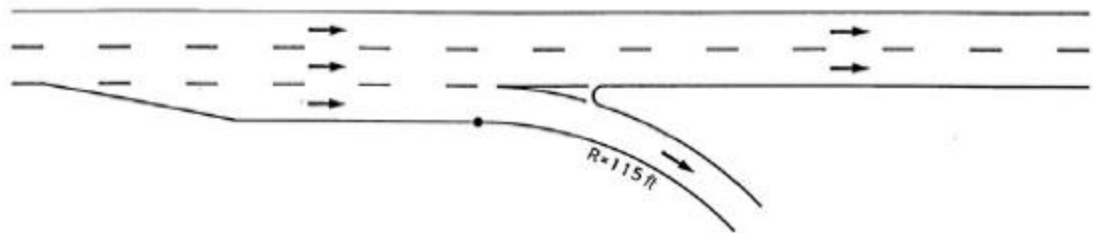
Exhibit 9-80. Minimum Design of Median Openings (WB-12 [WB-40] Design Vehicle, Control Radius of 23 m [75 ft])

Exhibit 9-81. Minimum Design of Median Openings (SU Design Vehicle, Control Radius of 15 m [50 ft])

Design for U-Turn (p141-143)

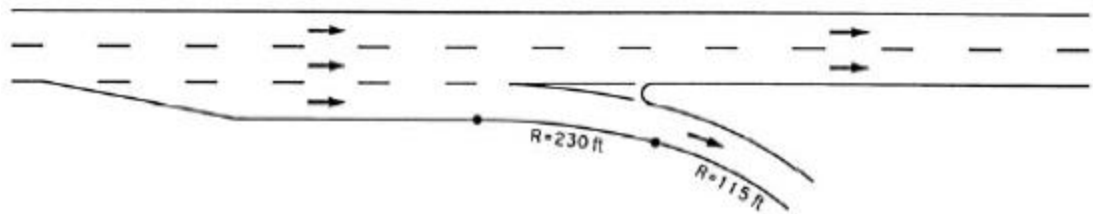
Median Width (ft)	Vehicles protected while standing in median opening
60	All
40	P and SU
32	P and SU
20	P only

Free flow turning roadways



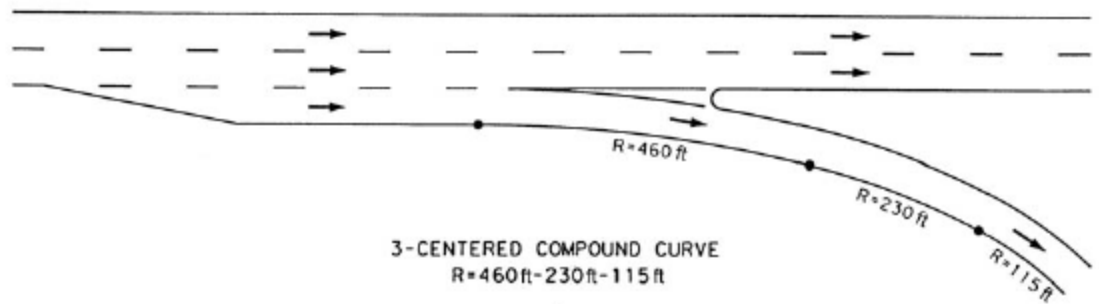
SIMPLE CURVE
 $R=115\text{ ft}$

-A-



COMPOUND CURVE
 $R=230\text{ ft AND }115\text{ ft}$

-B-

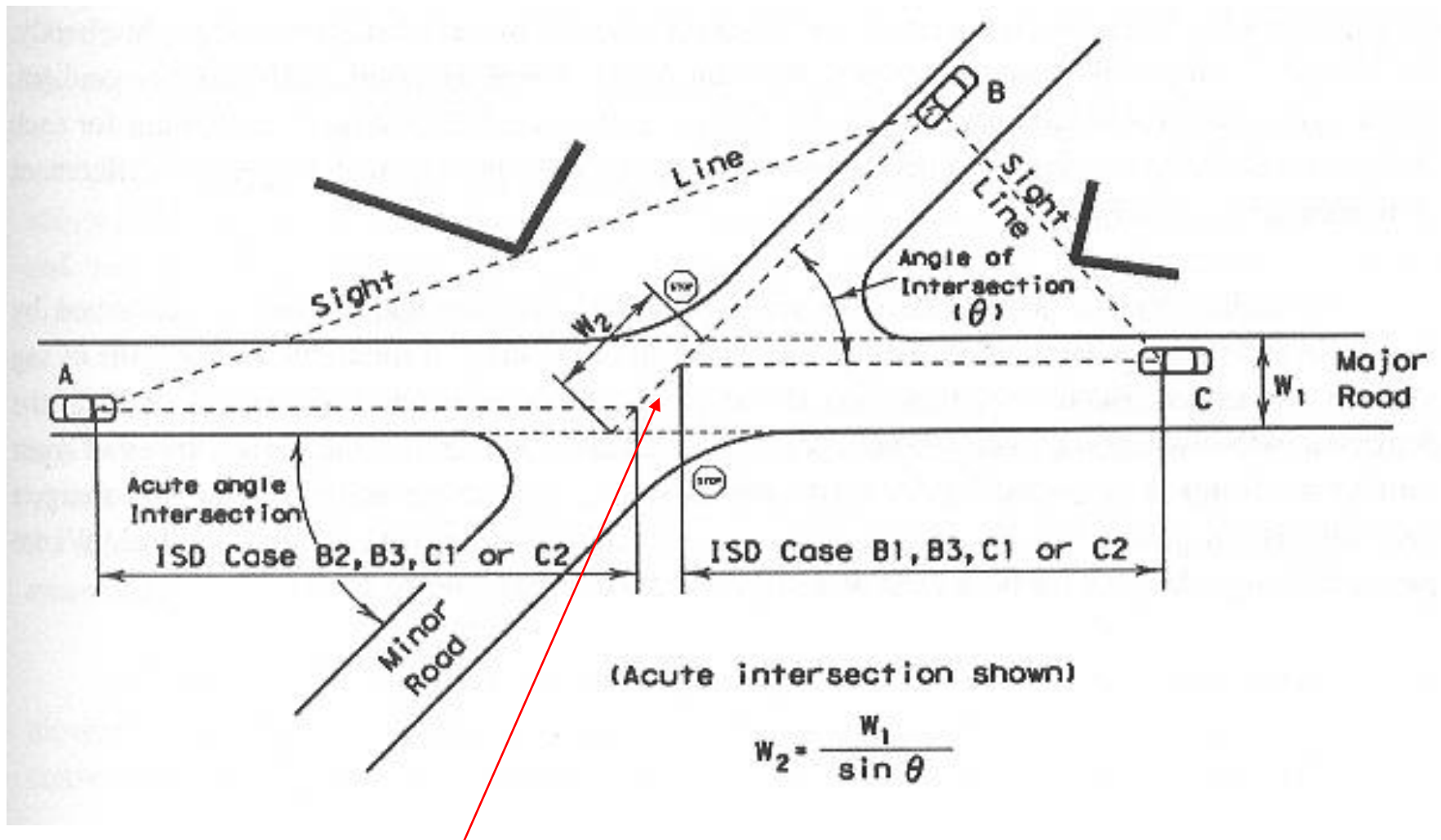


3-CENTERED COMPOUND CURVE
 $R=460\text{ ft}-230\text{ ft}-115\text{ ft}$

-C-

US CUSTOMARY

Exhibit 9-43. Use of Simple and Compound Curves at Free-Flow Turning Roadways
(Continued)



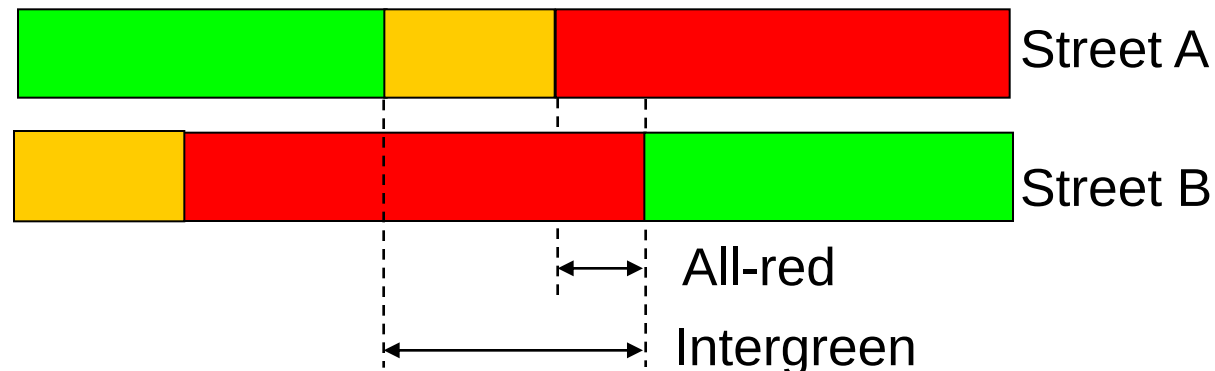
The length needs to be adjusted by dividing the total width of the lanes (+ median width) to be crossed by the sine of the intersection angle.

Types of Signal Controllers

- Pretimed
 - Fixed interval lengths in fixed sequence
- Semi-actuated (traffic-adjusted)
 - Predefined timing schemes selected based on traffic flow information
- Actuated
 - Varied length and/or sequence of signal indications
 - React to arrivals of vehicles/pedestrians
 - Isolated or coordinated

Basic Timing Elements

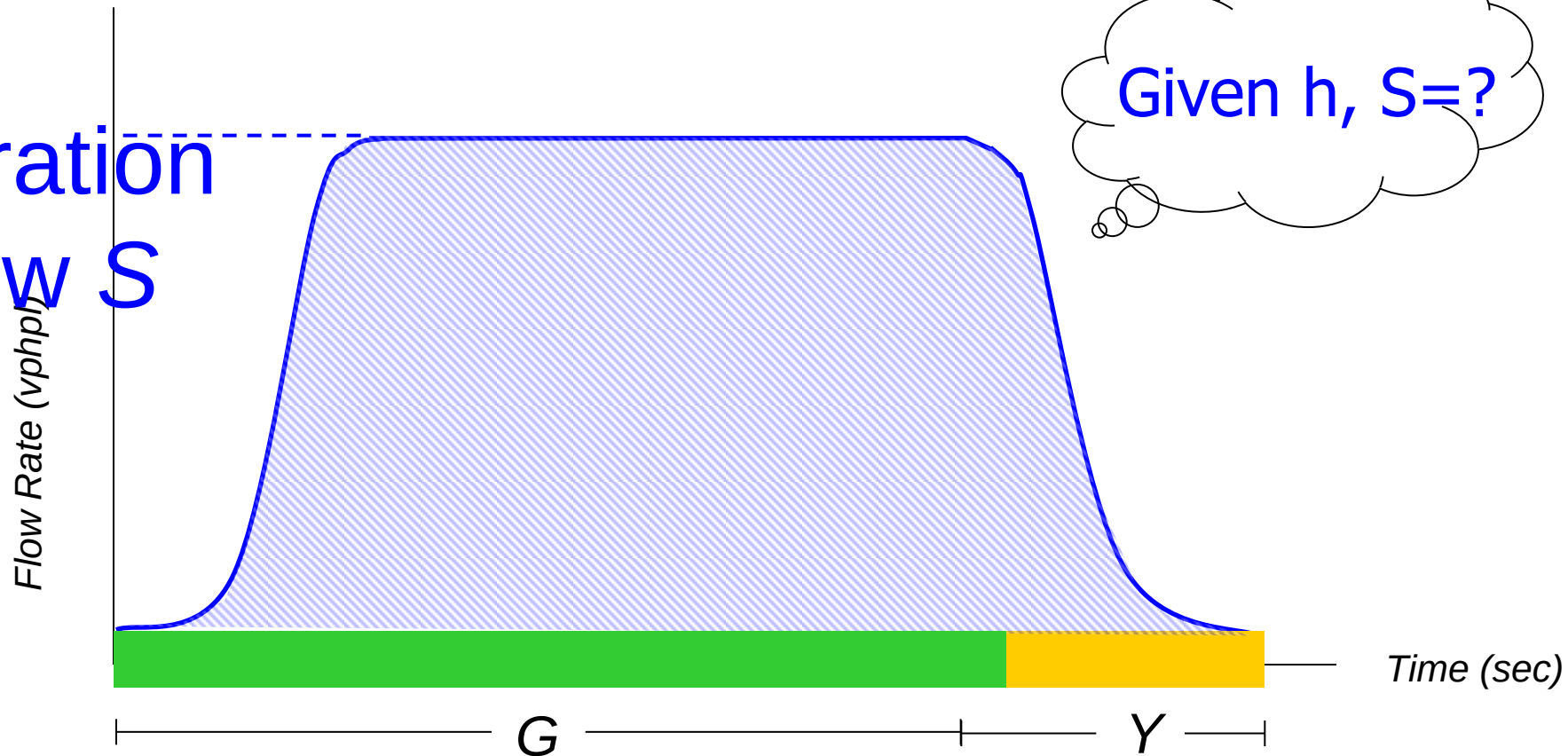
- Elements within a phase:
 - **Green interval**: the period of the phase during which the green signal is illuminated.
 - **Yellow/amber interval**: the portion of the phase during which the yellow light is illuminated.
 - **All-red interval**: the period during which the red light is illuminated for all approaches
 - **Intergreen interval**: the interval between the end of green for one phase and the beginning of green for another phase



Saturation Flow

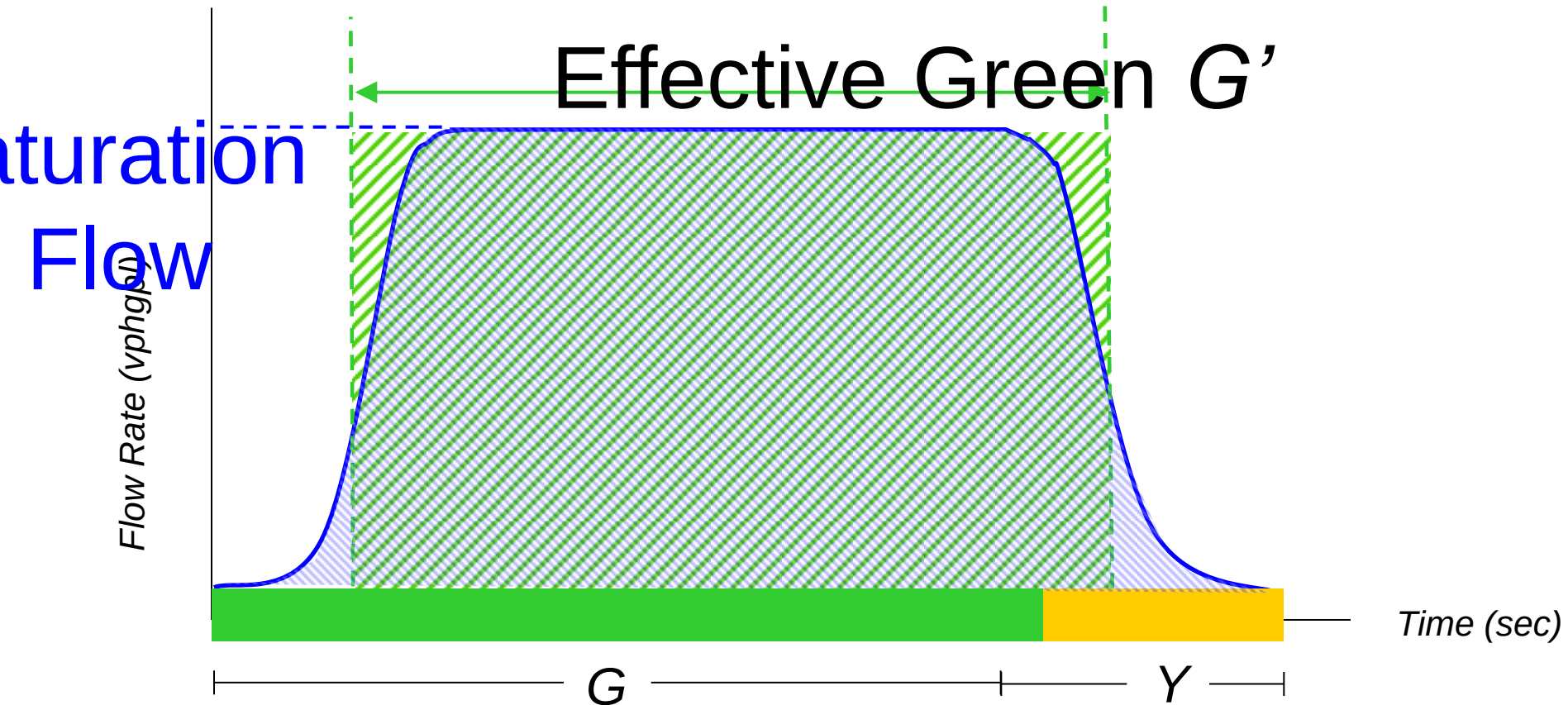
Number of vehicles that would pass through the intersection during an entire hour of green

Saturation
Flow S



Effective Green Time

Time during which the flow is assumed to take place at saturation flow



Lost Time

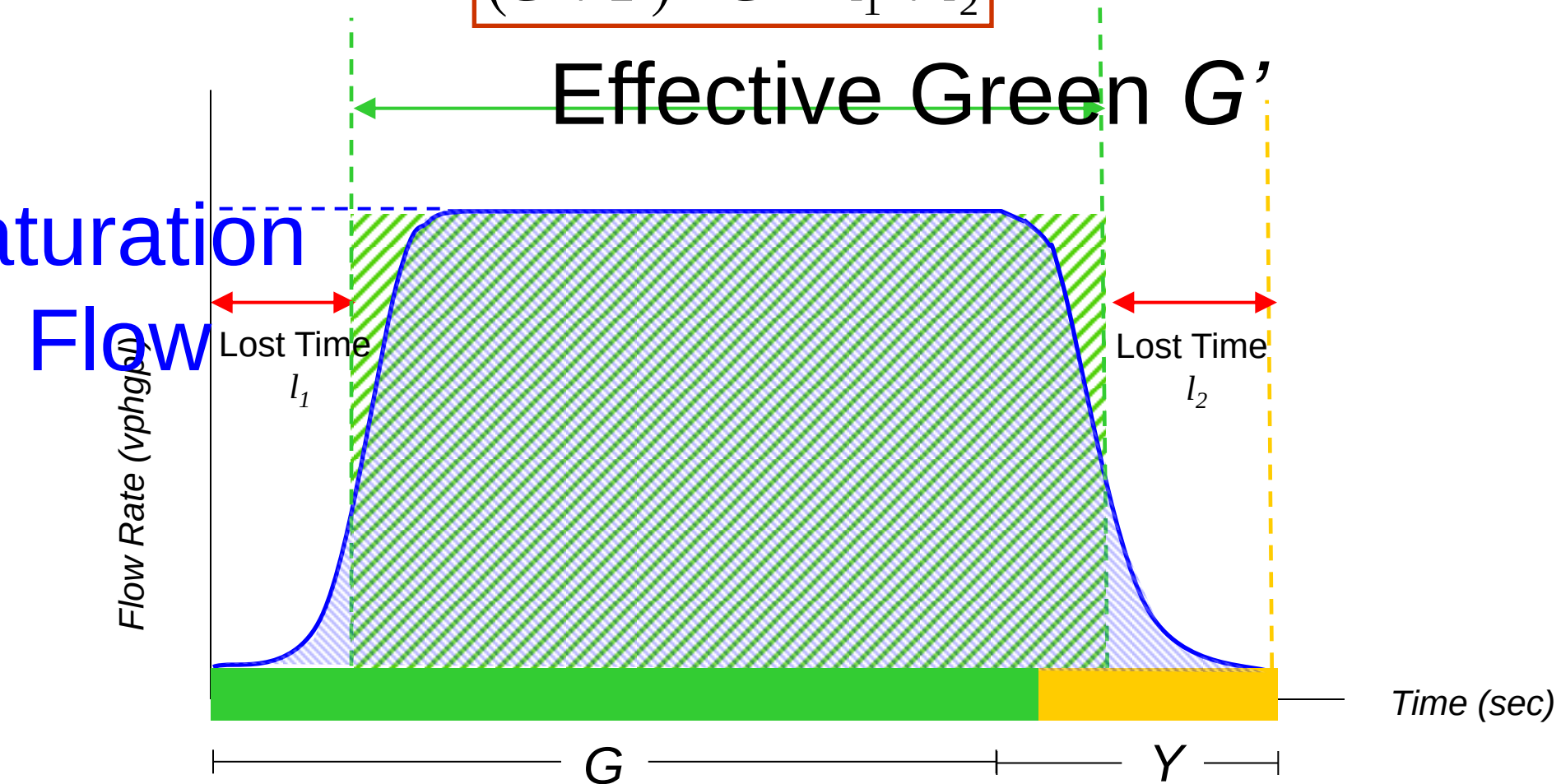
Time during which no flow takes place

$$(G + Y) - G' = l_1 + l_2$$



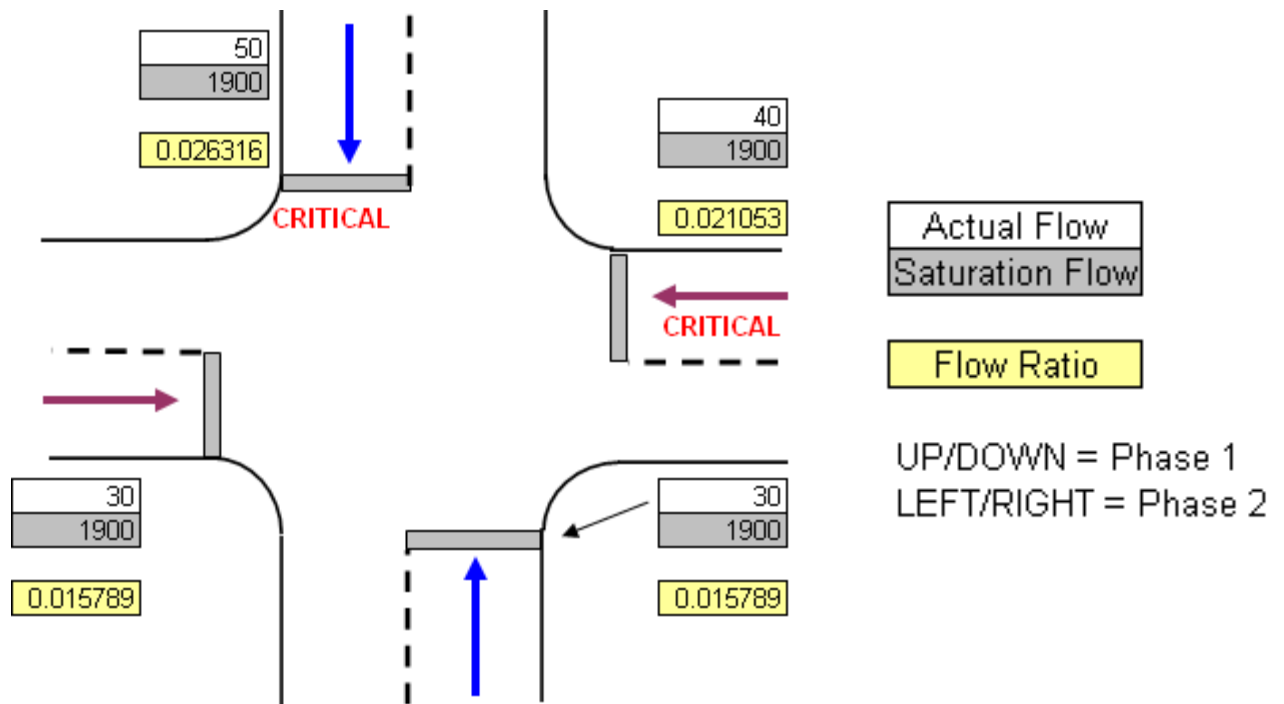
Lost Time

$$(G + Y) - G' = l_1 + l_2$$



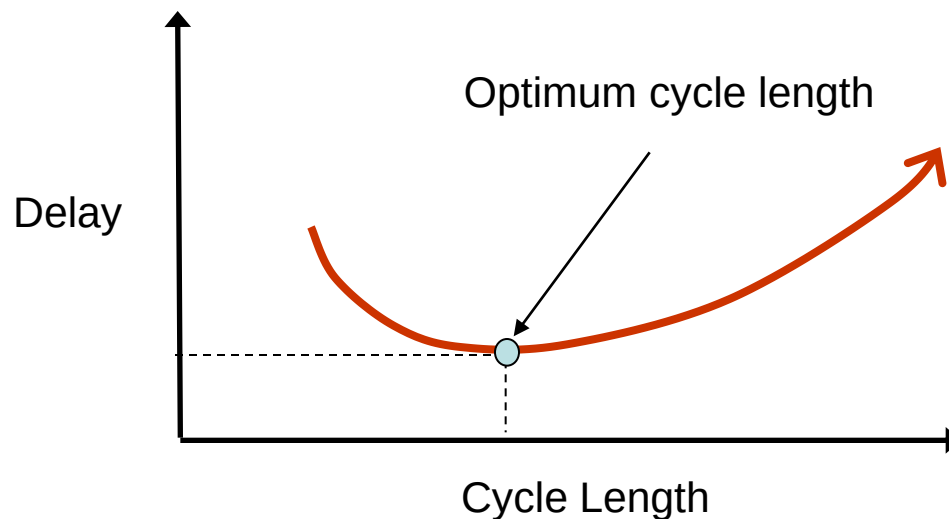
Critical Approach or Lane

- The approach or lane for a given phase that requires the most green time (highest flow ratio)
- Flow should be in **straight-through passenger-car units per hour** (e.g. 1 HV = 1.75 PCU)



Cycle Length Determination for Pretimed Signals

- Long enough to serve all critical movements, but no longer
- If too short: high lost/green time ratio
- If too long: lengthened queues



Webster's Method

- Most prevalent
- Minimizes intersection delay

$$C_o = \frac{1.5L + 5}{1 - \sum Y_i}$$

C_o = Optimum cycle length (sec)

L = Total lost time per cycle, usually taken as the sum of the total yellow and all-red intervals (sec) (i.e. total intergreen intervals)

Y_i = Ratio of the observed flow rate (in straight-through passenger cars per hour) to the saturation flow rate for the critical approach or lane in each phase

Allocate Green Time to Phases

- Split according to critical flow ratios across phases

$$G_i = (C_o - L) \frac{Y_i}{\sum Y_i}$$

$C_o - L$ = Available green time

Y_i = As before

Benefits of Traffic Signals

- Reduce right-angle collisions
- Orderly traffic
- Continuous flow
- Allow other vehicles and pedestrians to cross a heavy traffic stream
- Control traffic more economically than by manual methods

Drawbacks of Traffic Signals

- Unjustified, ill-designed, improperly operated signals
 - Increased rear-end collisions
 - Excessive delay
 - Disregard of signal indications
 - Circuitous travel by alternative routes