MK's Notes for
CIVL-4530/6970 Geometric Design

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Geometric design is the base of transportation,

providing fundamental concepts, terms, and fomulas.

Contents

1 Introduction and Highway Function

1.1 Objectives

1. Geometric Design concepts
2. Highway Funciton

1.2 Geometric Design Definition

1. fit the highway to the terrain
2. maintaining design standards for safety and performance

1.3 Geometric Design Basic

1. make criteria matches
   (a) driver expectancy/behavior
   (b) vehicle performance/behavior
2. balance safty, cost, mobility, community values, environmental, politics, liability, sustainable development, etc

1.4 AASHTO Role

1. American Association of State Highway and Transportation Officials
2. the membership of AASHTO consists of FHWA, and state DOTs

1.5 Reference - AASHTO publications

1. **a.k.a Green Book/PGDHS:** A Policy on Geometric Design of Highways and Streets, 2018, 7th Edition
2. Guidelines for Geometric Design of Very Low Volume Local Roads, 2001
3. A Guide to Achieving Flexibility in Highway Design, May 2004
4. Guide for the Planning, Design, and Operation of Pedestrian Facilities, July 2004
5. Guide for the Development of Bicycle Facilities, June 2012
6. Good for New Highway Design
7. TRB Special Report 214, Designing Safer Roads: Practices for Resurfacing, Restoration, and Rehabilitation for guidance.

1.6 Reference - ITE publications

ITE - Institute of Transportation Engineers. It is an international educational and scientific association of transportation professionals.

1. Urban Street Geometric Design Handbook, 2008
2. Freeway and Interchange Geometric Design Handbook, 2007
3. Designing Walkable Urban Thoroughfares: A Context Sensitive Approach, March 2010

1.7 design elements

Design elements affect design consistency, driver expectancy, and vehicular operation.

1. horizontal and vertical alignment
2. embankments and slopes
3. shoulders, crown and cross slope, superelevation
4. bridge widths
5. signing and delineation
6. guardrail and placement of utility poles or light supports

1.8 Highway Design Control Factors

1. Highway Function (Arterials, Collections, Locals)
2. Design speed of the facility
3. Physical characteristics of the "design vehicle"
4. Performance of the design vehicle (heavy trucks, RVs)
5. Acceptable degree of congestion

1.9 The first step of hightway design process!!!

the 1st step is to define the function of the facility
Then, define the LOS required to fullfill the function.
Next, LOS selects the design speed and the geometry criteria.

1.10 Highway functions

Highway Function: Arterials, Collections, Locals
Arterials: principal arterials, minor arterials
Mobility: the ability to move goods and passengers to their destination in a reasonable time
Accessibility: the ability to reach desired destination

1.11 Highway hierarchy of Movements - 6 stages

1. Main Movement
2. Transition
3. Distribution
4. Collection
5. Access
6. Termination

1.12 Hierarchy of Movements

Roadway Class	**% Through Movement**	**VMT in Rural**	**Miles in Rural**	**VMT in Urban**	**Miles in Urban**
Freeways	100%				
Arterials	60-80%	**45-75%**	6-12%	**65-80%**	15-25%
Collectors	40-60%	20-35%	20-25%	5-19%	5-10%
Local Streets	0-40%	5-20%	**65-75%**	10-30%	**65-80%**

1.13 Highway Design Volume

Highway Type	Approximate Design Speed	Approximate Design Volume
Freeway – free flow	70-75 mph	2400 veh/h/ln
Freeway – free flow	65 mph	2300 veh/h/ln
Rural Highways		
a) Multilane-one way		1600-2000 veh/h/ln
b) Two lane		2000-2800 veh/h
Urban Highways		
a) Arterials		See Highway Capacity Manual
b) Signalized intersections		1900 pc/h/ln
c) Unsignalized intersections		1100-2000 veh/h

1.14 Traffic Information for Roadway Designers

These traffic information should be available to the designer prior to or very early in the design process:

1. AADT for the current year: opening year (completion of construction), and design year
2. Existing hourly traffic volumes over a minimum of 24-hour period, including peak hour turning movements and pedestrian counts
3. Directional distribution factor (D_{30}).
4. 30th highest hour factor (K_{30}).
5. Truck factors (T) for daily and peak hour.
6. Design speed and proposed posted speed.
7. Design vehicle for geometric design.
8. Turning movements and diagrams for existing and proposed signalized intersections.
9. Special or unique traffic conditions, including during construction.
10. Crash history, including analyses at high crash locations within the project limits.
11. Recommendations regarding parking or other traffic restrictions.

1.15 Terms

1. cross section - A cross section refers to the vertical view of a roadway or highway at right angles to its centerline.
2. embankment - An embankment is a constructed mound of earth, stones, or other materials. Its purpose is to support the raising of a roadway or railway above the level of the surrounding ground surface.

3. cross slope - Cross slope plays a crucial role in ensuring proper drainage and safety on roadways.
4. crown - The crown of a highway refers to the cross-sectional shape of the road surface.
5. signing and delineation -
6. guardrail - A guardrail on a highway serves as a safety barrier designed to protect motorists.
7. guardrail and placement of utility poles or light supports -
8. detour - walkaround roadway
9. through movement - refers to the uninterrupted flow of vehicles or goods from one location to another
10. VMT - Vehicle Miles Traveled
11. open year and design year - open year means compeletion of construction.
12. AADT - the average daily volume of vehicle traffic of a year. It is calculated by dividing the total traffic volume for the year by 365 days.
13. D_{30} factor - Directional Distribution factor
14. K_{30} factor - the 30th highest hour factor

1.16 Rules

1.17 Formulas

1.18 Reference

2 Design Control and Criteria

2.1 Objectives

1. Design Vehicles, Driver and Traffic Characteristics
2. 13 AASHTO criteria
3. AASHTO administered, federal-wide
4. State-DOT administered - Green Book
5. local goverment administered - ordinance or code

2.2 Design vehicles

1. Design Vehicle
   Its weight, dimensions, and operating characteristics will be used to establish the geometric standards of the highway.
2. design vehicle P: passenger car
   (a) Geometry - length 19ft (5+11+3), width 7ft
   (b) Minimum turning path - outline 25.4ft, front wheel 23.8ft, CTR 21ft, min 14.4ft
3. WB-50 - length 55ft, width 8.5ft, height 13.5ft

ASSHTO guideline - Selection of design vehicle 1

1. parking lot - passenger car
2. intersection of local area - SU-30, 30ft
3. intersection of state highway and city street - City transit buses, 40ft
4. intersections of highways; low-volume county roads with ADT ¡ 400 - City bus (40ft, 84 passengers) or conventional bus(36ft, 64 passengers)
5. freeway ramp; arterial crossroads; intersections of state highways; with high volume of traffic - WB-40 to WB-62

2.3 Older Driver Deficiencies

1. Slower information processing
2. Slower reaction times
3. Slower decision making
4. Visual deterioration
5. Hearing deterioration
6. Decline in ability to judge time, speed, and distance
7. Limited depth perception
8. Limited physical mobility
9. Side effects from prescription drugs

2.4 LOS and ADT

acceptable LOS / level of "congestion" 2

Roadway	urban	rural level	rural rolling	rural mountainous
Freeway	C/D	B	B	C
Arterial	C/D	B	B	C
Collector	D	C	C	D
Local	D	D	D	D

2.5 13 AASHTO Criteria

1. design speed
2. lane width
3. shoulder width
4. bridge width
5. structural capacity
6.
7. horizontal alignment
8. vertical alignment
9. cross slope
10. grades
11. superelevation
12. horizontal clearance
13. vertical clearance

2.6 speed

1. running speed - the speed of an individual vehicle
2. design speed - AASHTO: max safe speed
3. operation speed - the 85th percentile of observed speed in free flow conditions
4. safty of over speed - ΔV: [0, 5] low; [5, 15] medium; [15, infinit] high

minimum design speed for **rural** roadways vs vehicle per day(VPD)

rural terrain	0-400	400-2000	over 2000
level	40	50	60
rolling	30	40	50
mountainous	20	30	40

2.7 lane width for urban and rural (1-2ft wider than urban)

Types	urban	rural
Freeway and Interstates:	12ft,	12ft
Ramp:	12-30ft	12-30ft
Arterial:	11-12ft,	10-12ft
Collections:	10-12ft,	10-12ft
local roads:	9-12ft,	9-12ft

2.8 cross slope

paved surfaces: 1.5-2%, typical 2% - Green Book
unpaved surfaces: 2-6% - Green Book
areas with high intensity rainfall: 2-2.5%
ALDOT use in 2 Counties: 2.2%

Table 1: Lane Widths for Different Types of Roadways

Type of Roadway	**Rural**		**Urban**	
	US (feet)	**Metric (meters)**	**US (feet)**	**Metric (meters)**
Freeway	14-16*	4.3-4.9*	14–16*	4.3–4.9*
Arterial	14-16	4.3-4.9	14–16	4.3–4.9
Collector	14	4.3	14	4.3
Local	14	4.3	14	4.3

Table 2: Functional Classification of Roadways

Criteria	**Local**	**Collector**	**Arterial**
Street pavement width	24 ft	22 ft (1), 31 ft	36 ft (2), 48 ft
Minimum horizontal curve radius	200 ft	350 ft	550 ft
Maximum grade (3)	15%	12%	8%
Minimum design speed for vertical curve	25 mi/h	35 mi/h	45 mi/h

2.9 Terms

SU - represents all single unit trucks and small buses, with length 35-60ft
ADT - average daily traffic
AADT - the annual average daily traffic, empersizing annual average
DHV - design hour volume
DDHV - The directional design hour volume
30HV - the 30th Highest Hour of Yearly Traffic - the 30th Hour volume
design speed (DS) - design maximum speed of a roadway
free flow speed (FFS) - the observed speed at which vehicles can travel with minimal delays and no restrictions from traffic signals, congestion, or other factors.
LOS - Characterization of operating conditions, related to speed, travel time, traffic density, freedom to maneuver
FFS is close to DS - It means a good design
K-factor - DHV = K * ADT, K is 8 to 12% for urban facilities; 12 to 18% for rural facilities.
D-factor - DDHV = D * DHV, D is 50% for urban highways; 55 - 80% for rural and suburban roads
DDHV = ADT (or AADT) * K * D
CMF - Crash Modification Factor

Cul-de-sac: deed end street

2.10 Rules

Tandem Axle - 2 axles which are very close
State maximum gross vehicle weight - 73,280 - 164,000 lbs
State maximum gross vehicle weight - 73,280 - 164,000 lbs

DHV = 8% - 12% ADT in urban area, refer to Green Book
30HV = 15% ADT in a typical rural arterial, refer to Green Book

2.11 Formulas

1 mile = 5,280 feet
1000 kg = 2204.62 lbs
1 foot = 0.3048 meters
1 lb = 16 oz
1 gallon = 3.785 liters (U.S. liquid gallon)
1 gallon = 4.546 liters (U.K. imperial gallon)

2.12 Reference

FHWA Website
http://safety.fhwa.dot.gov/geometric/pubs/mitigationstrategies/

3 Sight Distance (SD)

3.1 Objectives

1. describe various types of sight distance
2. determine sight distance requirements for stopping and passing maneuvers

3.2 key component of SD

1. PRT: the perception-reaction time required to initiate a maneuver (pre-maneuver phase)
2. MT: the time requried to safely complete a maneuver

driver's eye - 3.5ft high
Hazard - 2ft high

3.3 Sight Distance Types

1. stopping sight distance (SSD)
2. decision sight distance (DSD)
3. passing sight distance (PSD)
4. intersection sight distance (ISD)

3.4 SSD - stopping sight distance

SSD is a key input for geometric design, including horizontal and vertical alignment

PRT includes: recognize an object + decide a stop + react and prepare to apply the brake
Deceleration rate: $11.2 ft/sec^2$, 10th percentile deceleration rate, by AASHTO

$SSD = D_{p-r} + D_b$

D_{p-r}: in ft, perception-reaction distance

D_b: in ft, braking distance

$D_{p-r} = 1.47 \times 2.5s \times v = 3.675v$

D_{p-r}: in ft, perception-reaction distance

v: in mi/h, design speed

$$D_b = \frac{(v_0)^2 - (v_f)^2}{30(\frac{a}{g} \pm G)}$$

D_b: in ft, braking distance

v_0: in mi/h, design speed

v_f: in mi/h, final velocity

a: 11.2 ft/sec^2, deceleration rate, by AASHTO, in [10, 15]

g: 32.2 ft/sec^2

f = a/g: 0.35 by ASSHTO, coefficient of friction, 0.7 for dry roads, 0.3-0.4 for wed roads

G: grade, e.g. down grade: -0.06

3.5 SSD on vertical curve

crest curve:
- Driver eye height: 3.5ft
- Height of object in readway: 2.0ft

sag curve:
- headlight height: 2ft
- headlight beam angle: 1 degree (departure from horizontal, suggest changing to 0.75 degree)

3.6 DSS - decision sight distance

For A or B (avoidance maneuvers):
$DSD = 1.47V_t + 1.075(V^2/a)$

For C, D, and E:
$DSD = 1.47V_t$

3.7 DSS - decision sight distance

Decision sight distance for various conditions:

Avoidance Maneuver A: Stop on rural road, t = 3.0 s
Avoidance Maneuver B: Stop on urban road, t = 9.1 s

Avoidance Maneuver C: Speed/path/direction change on rural road, t varies between 10.2 and 11.2 s
Avoidance Maneuver D: Speed/path/direction change on suburban road, t varies between 12.1 and 12.9 s
Avoidance Maneuver E: Speed/path/direction change on urban road, t varies between 14.0 and 14.5 s

Source: AASHTO Green Book, 2011, Table 3-3

Table 3: U.S. Customary Decision Sight Distance

Design Speed (mph)	Decision Sight Distance (ft)				
	A	B	C	D	E
30	220	490	450	535	620
35	275	590	525	625	720
40	330	690	600	715	825
45	395	800	675	800	930
50	465	910	750	890	1030
55	535	1030	865	980	1135
60	610	1150	990	1125	1280
65	695	1275	1050	1220	1365
70	780	1410	1105	1275	1445
75	875	1545	1180	1365	1545
80	970	1685	1260	1455	1650

Table 4: Metric Decision Sight Distance

Design Speed (km/h)	DSD (m)				
	A	B	C	D	E
50	70	155	145	170	195
60	95	195	170	205	235
70	115	325	200	235	275
80	140	280	230	270	315
90	170	325	270	315	360
100	200	370	315	355	400
110	235	420	330	380	430
120	265	470	360	415	470
130	305	525	390	450	510

Table 5: U.S. Customary Assumed Speeds and Passing Sight Distance

Design Speed (mph)	Passed Vehicle (mph)	Passing Vehicle (mph)	Passing Sight Distance (ft)
20	8	20	400
25	13	25	450
30	18	30	500
35	23	35	550
40	28	40	600
45	33	45	700
50	38	50	800
55	43	55	900
60	48	60	1000
65	53	65	1100
70	58	70	1200
75	63	75	1300
80	68	80	1400

3.8 PSD - Passing sight distance

passing vehicle speed - passed vehicle speed >= 12 mi/h

On two-lane rural highways
overtaking and returning to lane
before opposing vehicle reaches passing vehicle

3.9 Passing sight distance assumptions - Green Book

1. Speeds of passing and opposing vehicles equal the design speed
2. Speed differential between the passing and passed vehicle is 12 mi/h
3. Design vehicle is passenger car for all vehicles involved
4. Perception-reaction time to decide to abort is 1 second
5. Deceleration rate in abort maneuver is $11.2ft/sec^2$
6. Headway at end of maneuver is 1 second

3.10 Intersection Sight Distance - ISD

Sighting Rod - 3.5 feet height Target Rod - 4.25 feet height Observer - 10 feet behind stop bar

3.11 Intersection sight distance fomulas

$$ISD = 1.47V_{major} \cdot t_g$$

V_{majro} : in mph, design speed of major road

t_g : in seconds, time gap for minor road vehicle to enter the major road

Table 6: Metric Passing Sight Distance

Design Speed (km/h)	Assumed Speeds Passed Vehicle (km/h)	Passing Vehicle (km/h)	PSD (m)
30	11	30	120
40	21	40	140
50	31	50	160
60	41	60	180
70	51	70	210
80	61	80	245
90	71	90	280
100	81	100	320
110	91	110	355
120	101	120	395
130	111	130	440

3.12 ISD - left turn

Design vehicle	**t_g in seconds, LT Time Gap**
Passenger car	7.5
Single-unit truck	9.5
Combination truck	11.5

1. **Left turn and multilanes**: If requiring to cross one more lane, +0.5s for passenger cars, +0.7s for trunks.
2. **Grade of minor road**: If the approach grade > +3%, add 0.2s per additional grade.

3.13 ISD - right turn

Design vehicle	**t_g in seconds, RT time gap**
Passenger car	6.5
Single-unit truck	8.5
Combination truck	10.5

1. **right turn and multilanes**: If requiring to cross one more lane, +0.5s for passenger cars, +0.7s for trunks.
2. **Grade of minor road**: If the approach grade > +3%, add 0.1s per additional grade.

3.14 Terms

3.15 Rules

3.16 Formulas

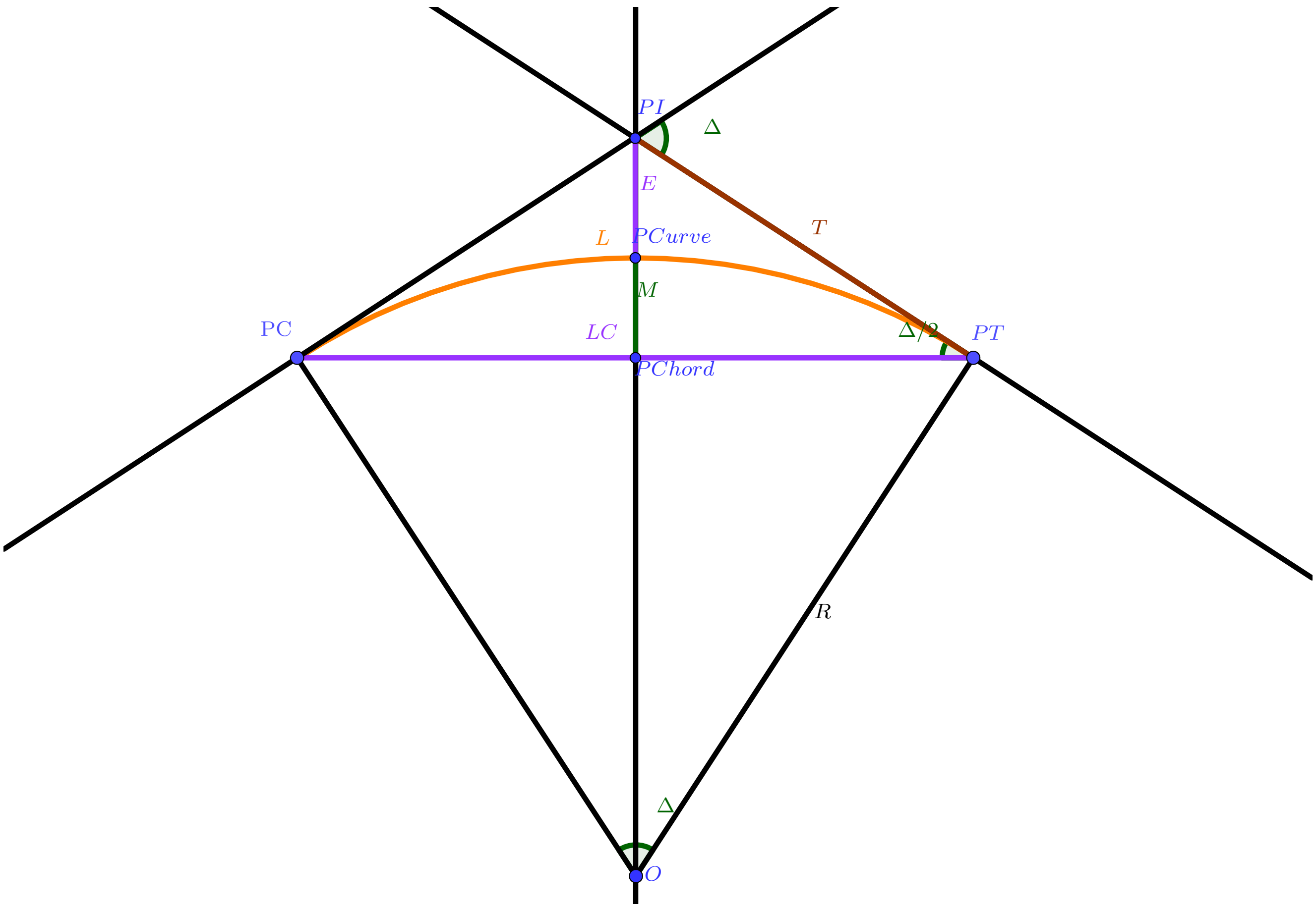
3.17 Reference

4 Horizontal Alignment

4.1 Objectives

1. Horizontal Curve Elements
2. Superelevation
3. Design Horizontal Curve

4.2 Horizontal Curve Diagram



4.3 Horizontal Curve diagram

Terms:

1. PI: point of intersection, intersection of tangent and curve
2. PC: point of curve(where curve starts), intersection of tangent and curve
3. PT: point of tangency(where curve ends), intersection of 2 tangents
4. PCurve: intersection of line PI-O and curve PC-PT
5. PChord: intersection of chord PC-PT and line PI-O
6.
7. R: the radius of the curve

8. D: in degree, degree of curve, the degree matches 100ft arc
   (a) highways:(small) D $->$ arc length of 100ft
   (b) railroads(big) D $->$ cord length of 100ft
9. Δ - the degree of the curve, **the same as the bearings of 2 tangents**
10. L: in feet, curve length
11. T: line segment from PI to PT/PC
12. E: external distance, line segment of PI-PCurve
13. M: middle ordinate, line segment of PCurve-PChord
14. LC: chord PC-PT
15. curvature - how big is a curve, $curvature = 1/R$

4.4 Horizontal Curve formulas

$$\frac{D}{100} = \frac{360}{2\pi R}$$
$$D = \frac{360 \cdot 100}{2\pi R}$$
$$L = 100 \cdot \Delta/D$$
$$L_{in\_meter} = 30.48 \cdot \Delta/D$$
$$T = R \cdot tan\frac{1}{2}\Delta$$
$$M = R(1 - cos\frac{1}{2}\Delta)$$
$$E = R(\frac{1}{cos\frac{1}{2}\Delta} - 1)$$
$$LC = 2R \cdot sin\frac{1}{2}\Delta$$

4.5 stationing calculations - for PI, PC and PT

Stationing is the concept of assigning distances along a line, such as a survey baseline (initial field survey) or center line (design)

52+48.63 means 52 hundreds 48 ft and .63 ft

Given PI, calculate the locations:

1. why???
2. PC = PI - T
3. PT = PC + L

4.6 bearings calculations

A bearing refers to the direction and orientation of a line

N 73°30'38"E
52+48.63 means 52 hundreds 48 ft and .63 ft

4.7 types of horizontal curves

1. simple
2. compound (R1 and R2)
3. reverse
4. spiral (change radius btw 2 Rs)

VDOT: The use of spiral transitions for compound and reverse curves on urban roadways should be avoided, ...

4.8 sight distance on curves

terms:

1. highway centerline $->$ highway radius
2. centerline inside a lane $->$ R_v
3. line of sight
4. sight obstruction
5. sight distance

sight distance fomula:

$$M_s = R_v \cdot (1 - cos_{degrees}\frac{90SSD}{\pi R_v})$$
$$M_s = R_v \cdot (1 - cos_{radians}\frac{SSD}{R_v})$$

M_s : **the middle ordinate, distance from centerline to obstruction**
R_v : **the radius of the curve, inside lance — for the centerline of the *1st* lane**
SSD : **the stopping sight distance**

4.9 superelevation - centrifugal force

suggestion value:

$1mph = 1.47ft/sec$

superelevation formula:

$$\frac{e+f}{1-ef} = \frac{v^2}{gR} = \frac{V^2}{15R}$$

minimam radius:

$$R_{min} = \frac{V^2}{15(f_s + e_{max})} = \frac{v^2}{g(f_s + e_{max})}$$

e: superelevation rate, e.g. 0.04

f: coefficient of friction

f_s: side friction, e.g. 0.10

g: 9.8, the acceleration of gravity

v: in ft/sec, the speed in ft/sec

V: in mph, the speed in mph

R: in ft, the radius of the curve in feet

4.10 superelevation - selection of e

1. too high or too low?
2. What factors should be considered?
3.
4. e $\leq$ 0.10 on any paved road
5. e $\leq$ 0.12 on unpaved roads
6. e $\leq$ 0.08 where there is ice and snow
7. e $\leq$ 0.06 in Illinois where ever practical
8. e $\leq$ 0.04 in Illinois for urban freeways

4.11 superelevation - transition design control

1. Tangent runout (TR): the distance needed to change from a normal crown section to a point where the outside lane(s) is level
2. Superelevation Runoff (L): the distance needed to change the cross slope from the end of TR to the design full superelevation rate.
3. IDOT practice: TR and 1/3 runoff on the tengent; 2/3 of runoff on the curve;
4. ASSHTO: placing the PC at between 60% and 80% of the transition length

5. ALDOT: 80/20 split (of the entire STL)
6. VDOT: this split is of the superelevation runoff portion only, not the entire STL
7. Many states, including Virginia, use 2:1 split

4.12 axis of rotation

Axis of Rotation is the point about which the pavement edges are revolved to superelevate the roadway.

1. typically, on undivided highways the centerline of roadway is the axis of rotation.
2. typicallly, divided highways rotate around the median edge
3. also, some roadway revolved about inside edge!

4.13 superelevation runoff fomula

superelevation runoff for *TWO-Lane* roads:
$L_{sro} \cong 30e(V+32)$, for 12 ft lans
$L_{sro} \cong 25e(V+32)$, for 10 ft lans
L_{sro} : superelevation runoff length
e: superelevation rate

full superelevation curve length:
$L_{full} = L_{curve} - 2L_{sro}$
L_{full} : full superelevation curve length
L_{curve} : horizontal curve length (arc length)

for multilane roads: (AASHTO Green Book)
times 1.5 for 4 lanes (2 in each direction)
times 2.0 for 6 lanes

4.14 tangent runout formula

tangent runout formula, given runoff:
$TR = L_{sro}\dfrac{NC}{e}$
TR: tengent runout
L_{sro}: superelevation runoff length
NC: normal crown rate

4.15 Terms

gradient: slope rate

4.16 Rules

4.17 Formulas

4.18 Reference

5 Vertical Alignment

5.1 Objectives

1. Understand basic philosophies in establishing a vertical alignment
2. Apply criteria for selection of grades
3. Design a vertical Curve

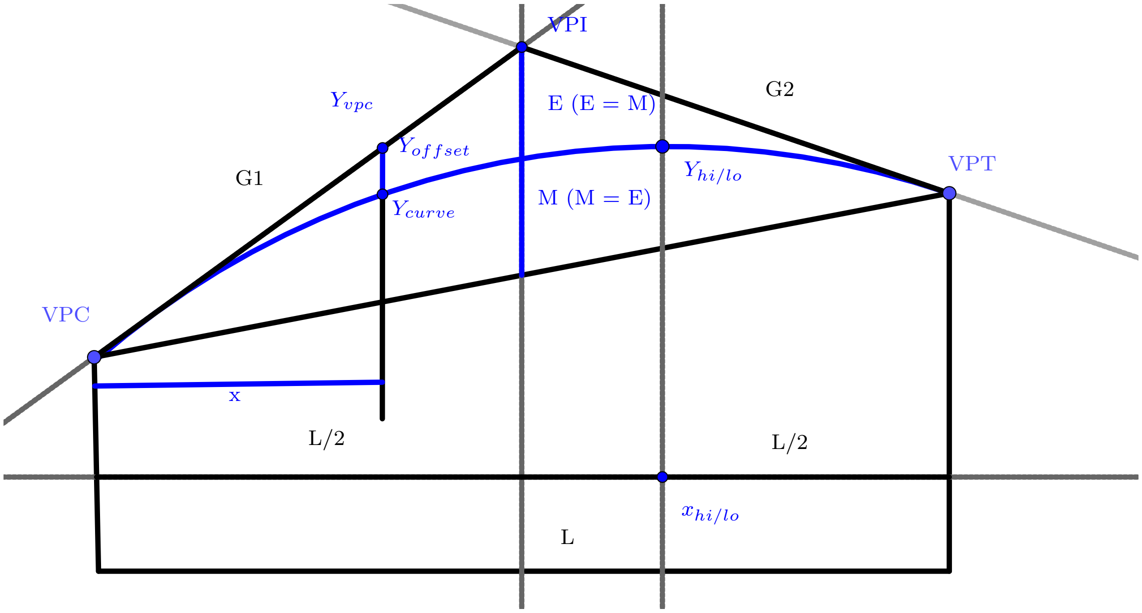
5.2 philosophies

1. conform to the existing terrain (within constraints of max grade and min lengths of vertical curves)
2. to minimize impacts (balance earthwork)
3. coordinate horizontal and vertical alignments (HC and VC)
   (a) avoid steep (near the max) grades and sharp (near min radius) horizontal curve
   (b) avoid placing the start of HC in the middle of VC; VC either at HC tangents or at HC vurves
   (c) avoid placing the start of HC at the bottom of a steep VC

5.3 maximum grades

1. Steepness and length heavily impacts heavy vehicles.
2. max grade design criteria is related with: design speed, the functional classification, and terrain
3. max grades: by AASHTO
   (a) freeway: 3-6%, +3.00% 70mph; max +4.00% for upgrade, max -5.00% for downgrade
   (b) arterials: +3.00% 60mph; up to +8.00% 40mph at mountainous
   (c) collectors: +4.00% 70mph; up to +14.00% 20 mph, mountainous
   (d) locals: up to +17.00% in mountainous terrain
4. min grades:
   (a) urban design(curb and gutter): an appropriate min grade is 0.5%, but grade of .30% ...
   (b) rural deisgn(shoulder and ditches): ... cross-slope is adaquate ...

5.4 Vertical Curve



If G_1 and G_2 are in slope, e.g. +0.02, x and L must in feet

$A = G_2 - G_1$

A: total change in grade, if negative, the curve is below the tangent

G_n: grade, like -0.08

$Y_{offset} = x^2\dfrac{A}{2L} = x^2\dfrac{G_2 - G_1}{2L}$

Y_{offset} : vertical offset from a tangent to a parabola, maybe negative!!!

$Y_{tan} = Y_{vpc} + G_1x$

Y_{tan} : tangent elevation

$Y_{curve} = Y_{vpc} + G_1x + \dfrac{A}{2L}x^2$

Y_{curve} : curve elevation

$Y_{tan} = Y_{offset} + Y_{curve}$

$x_{hi/lo} = L\dfrac{G_1}{G_1 - G_2}$

$x_{hi/lo}$: the highest/lowest point

5.5 stopping/passing sight distance on crest curves

$A = G_2 - G_1$

***SSD/PSD* minimum length of crest curve:**

$$L = \frac{|A|S^2}{200(\sqrt{h_1} + \sqrt{h_2})^2} \text{ when } S \leq L$$

$$L = 2S - \frac{200(\sqrt{h_1} + \sqrt{h_2})^2}{|A|} \text{ when } S \geq L$$

stopping: $h_1 = 3.5ft$, $h_2 = 2.0ft$

passing: $h_1 = 3.5ft$, $h_2 = 3.5ft$

***SSD* minimum length of crest curve:**

$$L_{SSD} = \frac{|A|S^2}{2158} \text{ when } S \leq L$$

$$L_{SSD} = 2S - \frac{2158}{|A|} \text{ when } S \geq L$$

A: in unit %, e.g. 3, the grade change of VC

L: the minimum length of the vertical curve ??? the arc length or the horizontal segment length???

S: stop sight distance, related with speed, reaction time, and coefficient of friction

h_1 : 3.5 feet, the driver eye height

h_2 : **2.0 feet, the object height**

5.6 sag sight distance

TODO diagram???

minimum length of sag curve

$$L = \frac{|A|S^2}{200(h + S \cdot tan\beta)} \text{ when } S \leq L$$

$$L = 2S - \frac{200(h + S \cdot tan\beta)}{|A|} \text{ when } S \geq L$$

$$L = \frac{|A|S^2}{400 + 3.5S} \text{ when } S \leq L$$

$$L = 2S - \frac{400 + 3.5S}{|A|} \text{ when } S \geq L$$

A: in unit %, e.g. 3, the grade change of VC

L: the horizontal length of sag curve

S: sag sight distance

h: 2 feet, the headlamp height

β : 1 degree, the headlamp beam angle

5.7 Vertical curve design - AASHTO elevation table - K^a factor

Another approach to determining curve length!

$L = K \cdot A$

L: in feet, curve length, minimum length for a given design speed

A: in unit %, change in grade, $A = G_2 - G_1$

K: rate of vertical curvature, K = required ft of curve length per 1% net change in grade

K: refter to K tables for a given design speed

K table for crest VC

K table for sag VC

5.8 K table for Crest VC, for a given design speed

5.9 K table for Sag VC, for a given design speed

5.10 elevation(height) in highway design

elevations are typically computed at the PVC, PVT, each 100-ft station, and the high or low point
procedure:

1. calc A - select vertical tangents
2. determine station and elevation of PVI
3. calculate the minimum length of the curve

Design Speed (mph)	**Stopping Sight Distance (ft)**	**Rate of Vertical Curvature, K^a**	
		Calculated	**Design**
15	80	3.0	3
20	115	6.1	7
25	155	11.1	12
30	200	18.5	19
35	250	29.0	29
40	305	43.1	44
45	360	60.1	61
50	425	83.7	84
55	495	113.5	114
60	570	150.6	151
65	645	192.8	193
70	730	246.9	247
75	820	311.6	312
80	910	383.7	384

Table 7: K Table for Crest Vertical Curve - U.S. Customary

Design Speed (mph)	**Stopping Sight Distance (ft)**	**Rate of Vertical Curvature, K^a**	
		Calculated	**Design**
15	80	9.4	10
20	115	16.5	17
25	155	25.5	26
30	200	36.4	37
35	250	49.0	49
40	305	63.4	64
45	360	78.1	79
50	425	95.7	96
55	495	114.9	115
60	570	135.7	136
65	645	156.5	157
70	730	180.3	181
75	820	205.6	206
80	910	231.0	231

Table 8: K Table for Sag Vertical Curve - U.S. Customary

(a) - typicallly using SSD and K factor

(b) - A vertical curve length can be selected first, and then checked to verify that K (based on L/A) $\geq K_{min}$

4. - Determine stations and elevations of PVC (BVC) and PVT (EVC)

$$
\begin{aligned}
Sta_{pvc} &= Sta_{pvi} - L/2 \\
Sta_{pvt} &= Sta_{pvi} + L/2 \\
Elev_{pvc} &= Elev_{pvi} - G_1 L/2 \\
Elev_{pvt} &= Elev_{pvi} + G_2 L/2
\end{aligned}
$$

G – grade in decimal, be sure to use correct sign on grade term

L – in ft, curve length

5. Compute elevations on initial tangent at full stations, typically to the nearest 0.01 ft

$$Elev_x \text{ on initial tangent} = Elev_{pvc} + G_1\{(x)/100\}$$

G – grade in percent; be sure to use correct sign on grade term

6. Compute the vertical distance y, **offset from tangent**, between initial tangent and curve

$$y = \frac{Ax^2}{200L}$$

y – in ft, offset from tangent

x – in ft, distance from PVC

7. Compute the elevation on the curve at each full station, or any station of interest!

$$Elev_x = \text{Elev on initial tangent} + offset$$

offset – positive for a sag curve, negative for a crest curve

8. Determine station and elevation of high or low point

$$Sta_{high/low} = Sta_{pvc} - \frac{G_1 \cdot L}{A}$$

$$Elev_{high/low} = Elev_{pvc} - \frac{G_1^2 \cdot L}{2A}\textbf{???}$$

5.11 Terms

gradient: slope rate grade: e.g. +4.00% a upward slope; -3.00% a downward slope

5.12 Rules

5.13 Formulas

5.14 Reference

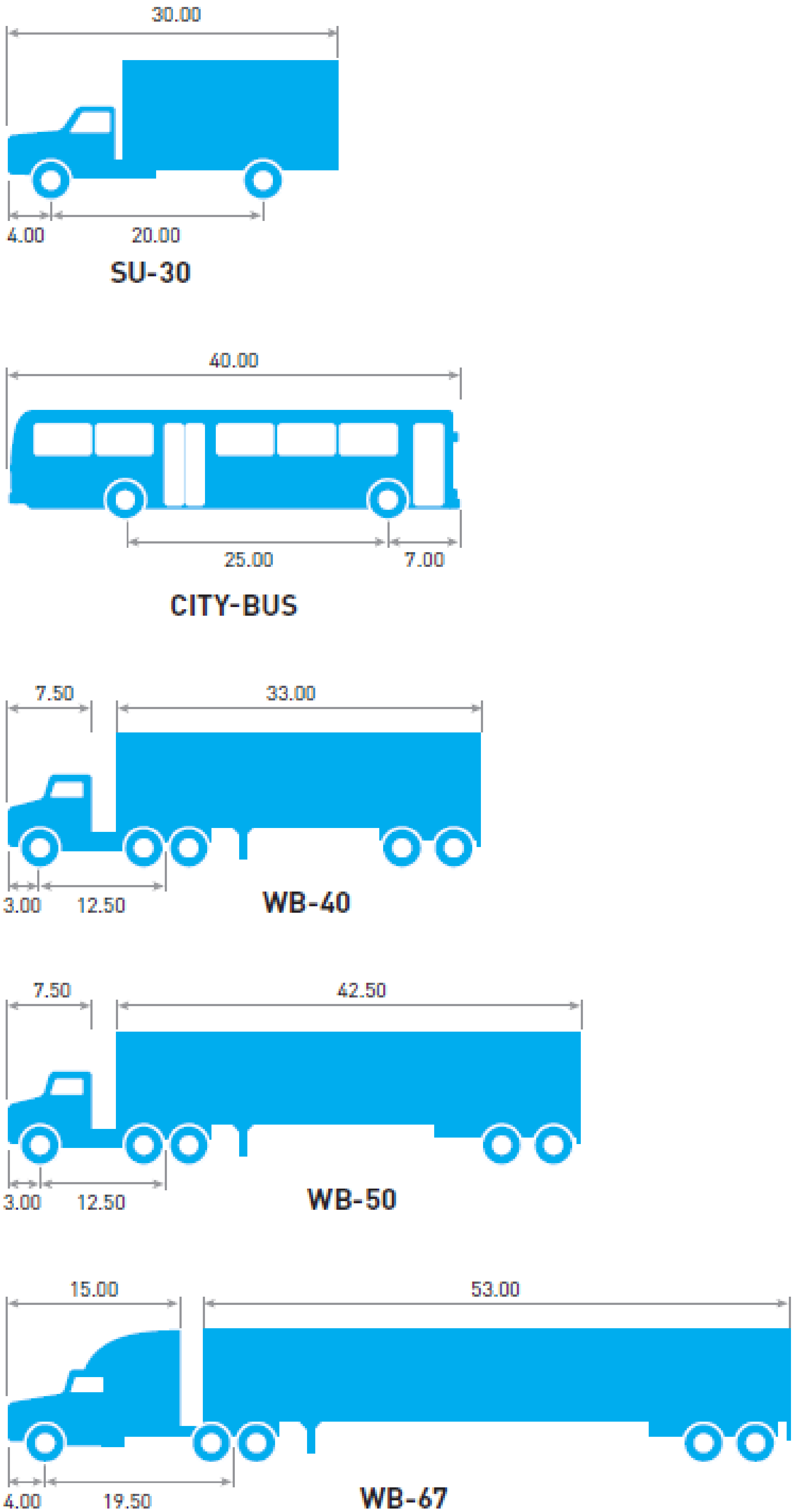


Figure 1: Design Vehicles

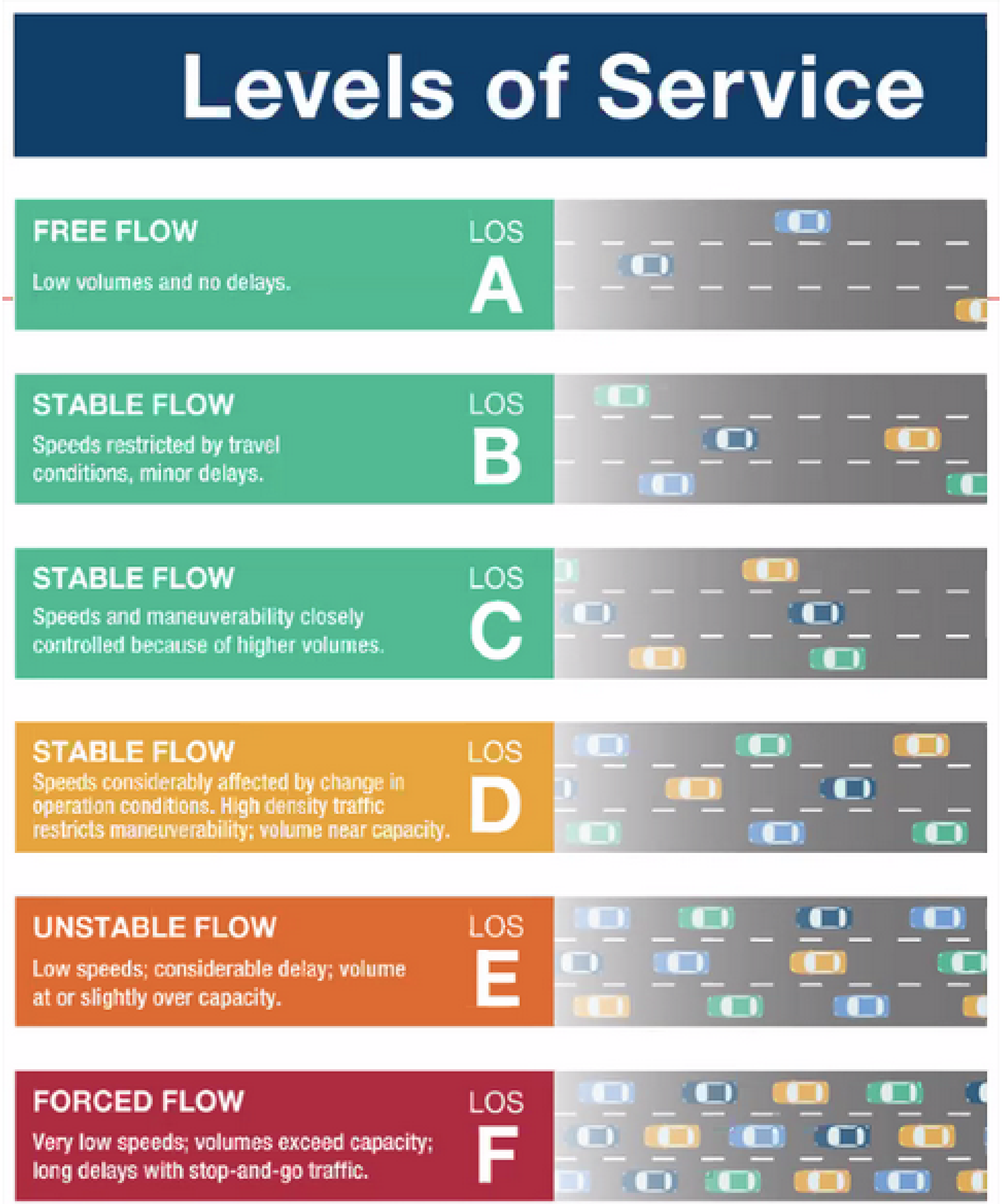


Figure 2: Level of Service

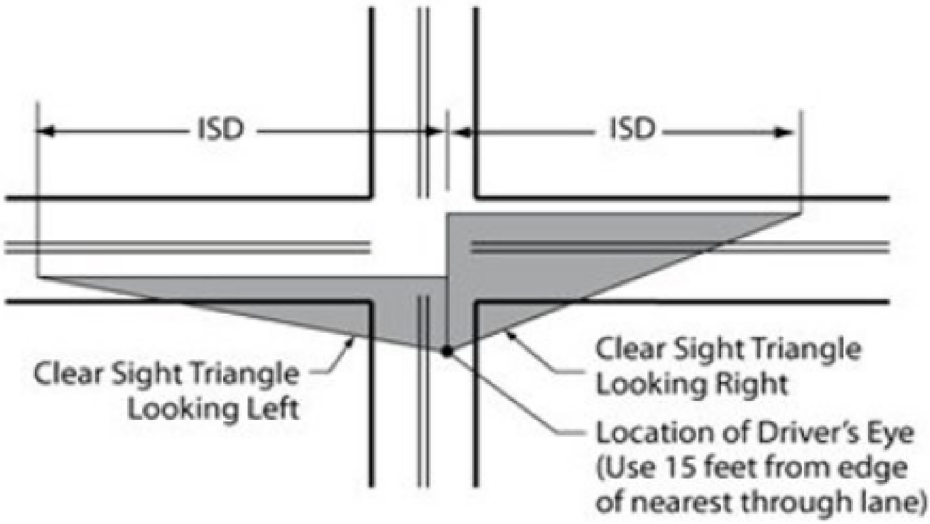


Figure 3: ISD - Left Turn

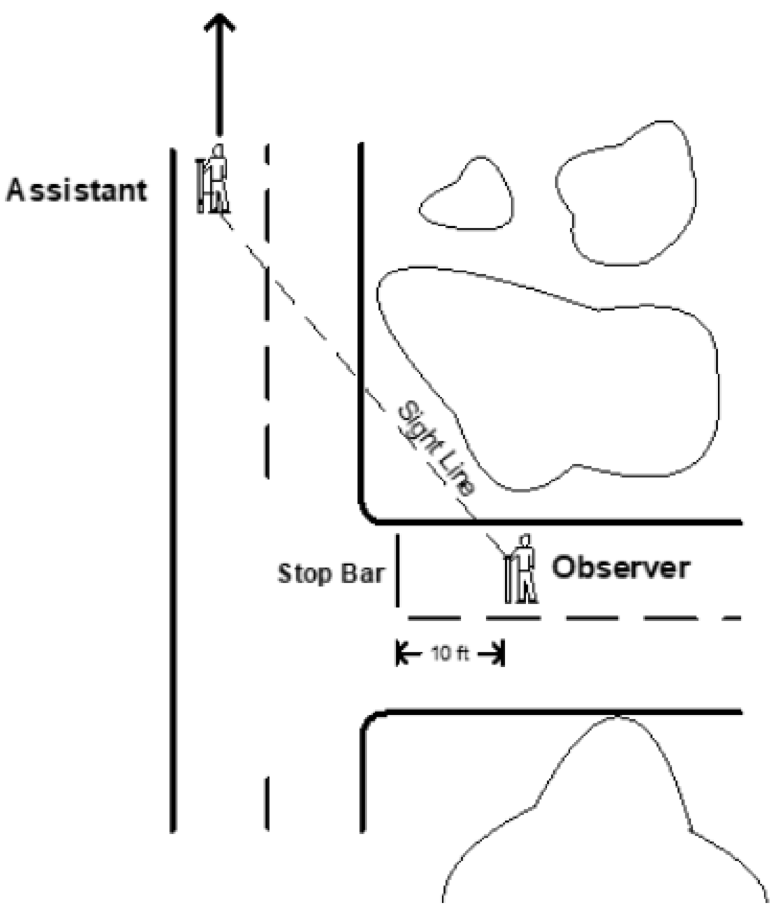


Figure 4: ISD - Observer