PDH-Pro.com

Roadway Horizontal Alignments II

Course Number: CE-03-909

PDH: 3

Approved for: AK, AL, AR, FL, GA, IA, IL, IN, KS, KY, LA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NV, NY, OH, OK, OR, PA, SC, SD, TN, TX, UT, VA, VT, WI, WV, and WY

New Jersey Professional Competency Approval #24GP00025600
North Carolina Approved Sponsor #S-0695
Maryland Approved Provider of Continuing Professional Competency
Indiana Continuing Education Provider #CE21800088
Florida Provider #0009553 License #868
NYSED Sponsor #274

This document is the course text. You may review this material at your leisure before or after you purchase the course. In order to obtain credit for this course, complete the following steps:

1) Log in to My Account and purchase the course. If you don't have an account, go to New User to create an account.

2) After the course has been purchased, review the technical material and then complete the quiz at your convenience.

3) A Certificate of Completion is available once you pass the exam (70% or greater). If a passing grade is not obtained, you may take the quiz as many times as necessary until a passing grade is obtained (up to one year from the purchase date).

If you have any questions or technical difficulties, please call (508) 298-4787 or email us at admin@PDH-Pro.com.

INTRODUCTION

The roadway **horizontal alignment** is a series of horizontal tangents (straight roadway sections), circular curves, and spiral transitions. It shows the proposed roadway location in relation to the existing terrain and adjacent land conditions. Together with the vertical alignment (grades and vertical curves) and roadway cross-sections (lanes, shoulders, curbs, medians, roadside slopes, ditches, sidewalks), the horizontal alignment (tangents and curves) helps to provide a three-dimensional roadway layout.

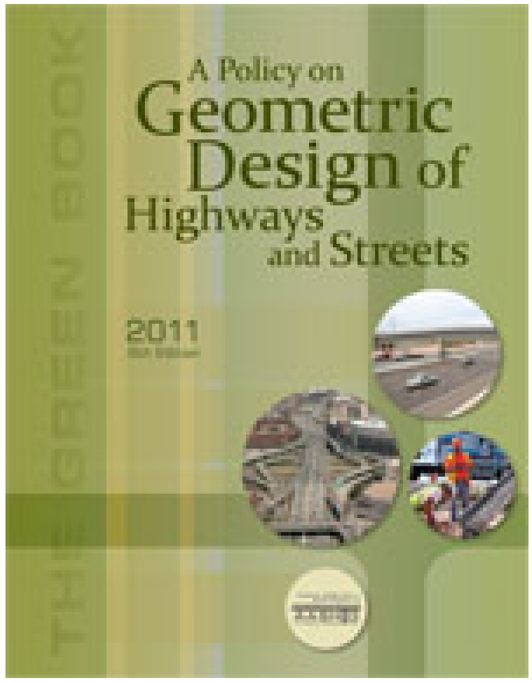
This course is the second of two that focuses on the geometric design of **horizontal alignments** for modern roads and highways. Its contents are intended to serve as guidance and not as an absolute standard or rule.

Upon course completion, you should be familiar with the general design of horizontal roadway alignments. The course objective is to give engineers and designers an in-depth look at the principles to be considered when designing horizontal alignments.

Subjects covered include:

- Design Considerations
  - *Cross slopes*
  - *Radii*
  - *Grades*
- Traveled-way Widening
  - *Design Methods*
- Sight Distance
  - *Stopping*
  - *Decision*
  - *Passing*
  - *Intersection*
- General Design Controls
- Coordination of Horizontal & Vertical Curves

A Policy on Geometric Design of Highways and Streets (also known as the “Green Book”) published by the American Association of State Highway and Transportation Officials (AASHTO) is considered to be the primary guidance for U.S. roadway design. For this course, Chapter 3 (Section 3.3 Horizontal Alignment) will be used exclusively for fundamental roadway geometric design principles.



BACKGROUND

Roadway geometric design consists of the following fundamental three-dimensional features:

Vertical alignment - grades and vertical curves

Horizontal alignment - tangents and curves

Cross section - lanes and shoulders, curbs, medians, roadside slopes and ditches, sidewalks

Combined, these elements contribute to the roadway's operational quality and safety by providing a smooth-flowing, crash-free facility.

Engineers must understand how all of the roadway elements contribute to overall safety and operation. Applying design standards and criteria to 'solve' a problem is not enough.

The fundamental objective of good geometric design will remain as it has always been **– to produce a roadway that is safe, efficient, reasonably economic and sensitive to conflicting concerns.**

TRAVELED-WAY WIDENING ON HORIZONTAL CURVES

Often, traveled ways on horizontal curves may need to be widened to produce operational characteristics that are similar to tangent sections. While the need for widening on modern highways is less than that for past roadways, there are some cases where *speed, curvature, or width* may require appropriate traveled way widening.

Primary Reasons for Widening on Curves

- Design vehicle off tracks when negotiating curve
- Driver difficulty in remaining in center of the lane

AASHTO Equation 3-34 calculates the amount of traveled way widening for horizontal curves by using the difference between the width needed on the curve and the tangent width. The needed curve width has several variables: track width for passing/meeting vehicles; lateral vehicle clearance; width of inner lane vehicle front overhang; curve difficulty allowance width.

In most cases, the design vehicle is a truck (typically WB-62) since off tracking is much greater for heavy vehicles versus passenger cars.

Since sight distance can be restricted when meeting opposing vehicles on curved two-way roads, widening procedures for two-lane, one-way traveled way (divided highway) should be similar to those for two-lane, two-way roadways.

Any widening for horizontal curves should transition gradually on the approaches to align traveled way edges and vehicle paths. AASHTO Equation 3-35 provides values for the width of traveled way on curves.

Curve Widening Design Concerns

- Widen only the inside edge of traveled way for simple curves
- Widen on the inside edge or equally divided from the centerline for spirals
- Transition gradually over the length (typically 100 to 200 ft) to make all traveled way fully usable
- Avoid tangent transition edges – no angular breaks at pavement edges
- One-half to two-thirds transition length should be along tangent sections for roads without spirals
- Width increases should be distributed along the spiral length for highways with spirals
- Fully detail widening areas on construction plans

Factors for determining turning roadway widths at intersections include:

- Expected speed
- Curve radius: combined with design vehicle track width determine turning roadway width
- Types of vehicles: size and frequency of users or expected users

Turning roadways are classified operationally as:

One-lane (with or without passing opportunities)

or *two-lane (one-way or two-way)*

Design Methods for Turning Roadways

Case I One-lane, one-way operation
No passing stalled vehicles provision
For minor turning movements, moderate turning volumes, short connecting roadway
Remote chance of vehicle breakdown
Preferable sloping curb or flush edge of traveled way

Case II One-lane, one-way operation
Contains passing provision for stalled vehicles
Low speeds with adequate passing clearance
Sufficient widths for all turning movements of moderate to heavy traffic volumes within capacity of single-lane connection
For breakdowns, low traffic can be maintained

Case III Two-lane operation, either one or two-way
Two lanes necessary for traffic volume

Since precise data regarding traffic volumes for each vehicle type is not readily available, traffic conditions used to define turning roadway widths are described in broad terms.

Traffic Conditions for Turning Roadway Widths

Traffic Condition A	Predominantly Passenger Car (P) vehicles Some Single-Unit Trucks (SU-30) Small volume of trucks with occasional large truck
Traffic Condition B	Majority of Single-Unit Trucks (SU-30) Some tractor- semitrailer combination trucks (WB-40) Moderate volume of trucks - 5 to 10%
Traffic Condition C	Predominantly tractor-semitrailer combo (WB-40) More and larger trucks

Widths for turning roadways include shoulders or lateral clearance outside the traveled way. Shoulder widths may vary from none (curbed urban streets) to open-highway cross-section.

Table 3-30. Range of Usable Shoulder Widths or Equivalent Lateral Clearances Outside of Turning Roadways, Not on Structure

	Metric		U.S. Customary	
Turning Roadway Condition	Shoulder Width or Lateral Clearance Outside of Traveled-Way Edge (m)		Shoulder Width or Lateral Clearance Outside of Traveled-Way Edge (ft)	
	Left	Right	Left	Right
Short length, usually within channelized intersection	0.6 to 1.2	0.6 to 1.2	2 to 4	2 to 4
Intermediate to long length or in cut or on fill	1.2 to 3.0	1.8 to 3.6	4 to 10	6 to 12

Note: All dimensions should be increased, where appropriate, for sight distance.

Source: AASHTO "Green Book" Table 3-30

For roadways without curbs or with sloping curbs, adjacent shoulders should match the type and cross section of the approaches.

If roadside barriers are present, shoulder widths should be measured to the face of barrier with a graded width of 2.0 feet.

For other than low-volume roadways, right shoulders should be stabilized a minimum of 4.0 feet.

SIGHT DISTANCE

Sight distance is the length or distance of roadway visible to the driver. This is a major design control for vertical alignments and is essential for the safe and efficient operation of vehicles. This distance is dependent on the driver's eye height, the specified object height, and the height/position of sight obstructions. The three-dimensional features of the roadway should provide a minimum sight line for safe operations.

Sight Distance Criteria

Height of Driver's Eye:	3.50 feet above road surface (passenger vehicles)
	7.60 feet above road surface (trucks)
Height of Object:	2.00 feet above road surface (stopping & decision)
	3.50 feet above road surface (passing & intersection)

Due to differences in driver needs, various types of sight distance apply to geometric design - **Stopping,** **Decision,** **Passing,** and **Intersection**.

STOPPING SIGHT DISTANCE (SSD)

Stopping sight distance is considered to be the most basic form of sight distance. This distance is the length of roadway needed for a vehicle traveling at design speed to stop before reaching a stationary object in the road. Ideally, all of the roadway should provide stopping sight distance consistent with its design speed. However, this distance can be affected by both horizontal and vertical geometric features.

Stopping sight distance is composed of two distances:

(1) **Brake Reaction Time** starts upon driver recognition of a roadway obstacle until application of the vehicle's brakes. Typically, the driver not only needs to see the object but also recognize it as a potential hazard. The time required to make this determination can widely

vary based on the object's distance, visibility, roadway conditions, vehicle speed, type of obstacle, etc.

Perception → Braking

From various studies, it was shown that the required brake reaction time needed to be long enough to encompass the majority of driver reaction times under most roadway conditions. A brake reaction time of 2.5 seconds met the capabilities of most drivers – including older drivers.

The recommended brake reaction time of **2.5 seconds** exceeds the 90^{th} percentile of driver reaction time and is considered adequate for typical roadway conditions – but not for most complex driving conditions that may be encountered.

(2) **Braking Distance** – Roadway distance traveled by a vehicle during braking (from the instant of brake application)

Braking → Stopping

Using the following equation, the approximate braking distance (d_B) may be calculated for a vehicle traveling at design speed on a level roadway. The recommended deceleration rate (a) of **11.2 ft/s²** has shown to be suitable since 90% of all drivers decelerate at greater values. This deceleration rate is fairly comfortable and allows drivers to maintain steering control.

$$d_B = 1.075\frac{V^2}{a}$$

d_B = braking distance (feet)

V = design speed (mph)

a = deceleration rate (ft/sec^2)

For roadways on a grade, the braking distance can be determined by:

$$d_B = \frac{V^2}{30\left[\left(\frac{a}{32.2}\right) +/- G\right]}$$

d_B = braking distance on grade (feet)

V = design speed (mph)

a = deceleration rate (ft/sec^2)

G = grade (ft/ft)

Stopping distances for downgrades are longer than those needed for level roads while those on upgrades are shorter.

The Stopping Sight Distance formula is a function of initial speed, braking friction, perception/reaction time, and roadway grade that contains assumptions about the driver's eye height (3.5 feet) and the size of object in the road (2 feet).

$$SSD = 1.47Vt + 1.075\frac{V^2}{a}$$

SSD = stopping sight distance (feet)

V = design speed (mph)

a = deceleration rate (ft/sec^2)

Table 3-1. Stopping Sight Distance on Level Roadways

Metric					U.S. Customary				
Design Speed (km/h)	Brake Reaction Distance (m)	Braking Distance on Level (m)	Stopping Sight Distance Calculat-ed (m)	Stopping Sight Distance Design (m)	Design Speed (mph)	Brake Reaction Distance (ft)	Braking Distance on Level (ft)	Stopping Sight Distance Calculat-ed (ft)	Stopping Sight Distance Design (ft)
20	13.9	4.6	18.5	20	15	55.1	21.6	76.7	80
30	20.9	10.3	31.2	35	20	73.5	38.4	111.9	115
40	27.8	18.4	46.2	50	25	91.9	60.0	151.9	155
50	34.8	28.7	63.5	65	30	110.3	86.4	196.7	200
60	41.7	41.3	83.0	85	35	128.6	117.6	246.2	250
70	48.7	56.2	104.9	105	40	147.0	153.6	300.6	305
80	55.6	73.4	129.0	130	45	165.4	194.4	359.8	360
90	62.6	92.9	155.5	160	50	183.8	240.0	423.8	425
100	69.5	114.7	184.2	185	55	202.1	290.3	492.4	495
110	76.5	138.8	215.3	220	60	220.5	345.5	566.0	570
120	83.4	165.2	248.6	250	65	238.9	405.5	644.4	645
130	90.4	193.8	284.2	285	70	257.3	470.3	727.6	730
					75	275.6	539.9	815.5	820
					80	294.0	614.3	908.3	910

Note: Brake reaction distance predicated on a time of 2.5 s; deceleration rate of 3.4 m/s^2 [11.2 ft/s^2] used to determine calculated sight distance.

Source: AASHTO "Green Book" Table 3-1

Limitations of the AASHTO Model

- Does not fully account for heavy vehicles (longer stopping times)
- Does not differentiate between various highway types
- Does not recognize differing roadway conditions

Proper roadway design should address these variables by providing more than minimum stopping sight distance at locations with vehicle conflicts or hazardous conditions (sharp curves, cross-section changes, intersections, etc.).

DECISION SIGHT DISTANCE (DSD)

Certain situations requiring complex decisions or maneuvers (unexpected conflicts, navigational needs, roadway changes, etc.) can place extra demands on drivers. These circumstances usually require longer sight distances than those for stopping.

Decision sight distance recognizes these needs and is composed of the following required actions:

Detect unexpected/unusual conflict
Recognize potential risk
Select appropriate speed /path
Initiate and complete safe maneuver

Decision sight distance values are substantially greater than those for Stopping Sight Distance since DSD provides an additional margin of error and sufficient maneuver length at vehicle speeds – *rather than just stopping*.

Decision sight distance is needed for a variety of roadway environments – such as bridges, alignment changes, interchanges, intersections, lane drops, congested intersections, median crossovers, roadway cross-section changes, toll facilities, and unusual geometric configurations.

DSD values depend on whether the roadway's location is rural or urban, and the type of avoidance maneuver required.

Avoidance Maneuver	Condition	Time (sec)
A	Stop on rural road	3.0
B	Stop on urban road	9.1
C	Change on rural road	10.2 to 11.2
D	Change on suburban road	12.1 to 12.9
E	Change on urban road	14.0 to 14.5

The "Green Book" provides tabular decision sight distances to provide appropriate values for critical locations, and to furnish suitable evaluation criteria of available sight distances. Critical decision points need to have sufficient DSD.

Table 3-3. Decision Sight Distance

Metric						U.S. Customary					
Design Speed (km/h)	Decision Sight Distance (m) Avoidance Maneuver					Design Speed (mph)	Decision Sight Distance (ft) Avoidance Maneuver				
	A	B	C	D	E		A	B	C	D	E
50	70	155	145	170	195	30	220	490	450	535	620
60	95	195	170	205	235	35	275	590	525	625	720
70	115	235	200	235	275	40	330	690	600	715	825
80	140	280	230	270	315	45	395	800	675	800	930
90	170	325	270	315	360	50	465	910	750	890	1030
100	200	370	315	355	400	55	535	1030	865	980	1135
110	235	420	330	380	430	60	610	1150	990	1125	1280
120	265	470	360	415	470	65	695	1275	1050	1220	1365
130	305	525	390	450	510	70	780	1410	1105	1275	1445
						75	875	1545	1180	1365	1545
						80	970	1685	1260	1455	1650

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" Table 3-3

The pre-maneuver time for avoidance maneuvers is greater than the brake reaction time for Stopping Sight Distance. This gives drivers extra time to recognize the situation, identify alternatives, and initiate a response. DSD pre-maneuver components typically range from **3.0 to 9.1 seconds.**

For Avoidance Maneuvers A and B, the braking distance (for design speed) was added to the pre-maneuver component. Decision sight distances for **Avoidance Maneuvers A and B** can be calculated using the following formula:

$$DSD = 1.47Vt + 1.075\frac{V^2}{a}$$

DSD = decision sight distance (feet)

V = design speed (mph)

a = driver deceleration rate (ft/sec^2)

t = pre-maneuver time (seconds)

For Avoidance Maneuvers C thru E, the braking component is replaced with maneuver distance based on times (3.5 to 4.5 seconds) that decrease with increasing speed.

Decision sight distances for **Avoidance Maneuvers C, D, and E** can be calculated from the following equation:

$$DSD = 1.47Vt$$

DSD = decision sight distance (feet)

V = design speed (mph)

t = total pre-maneuver and maneuver time (seconds)

PASSING SIGHT DISTANCE

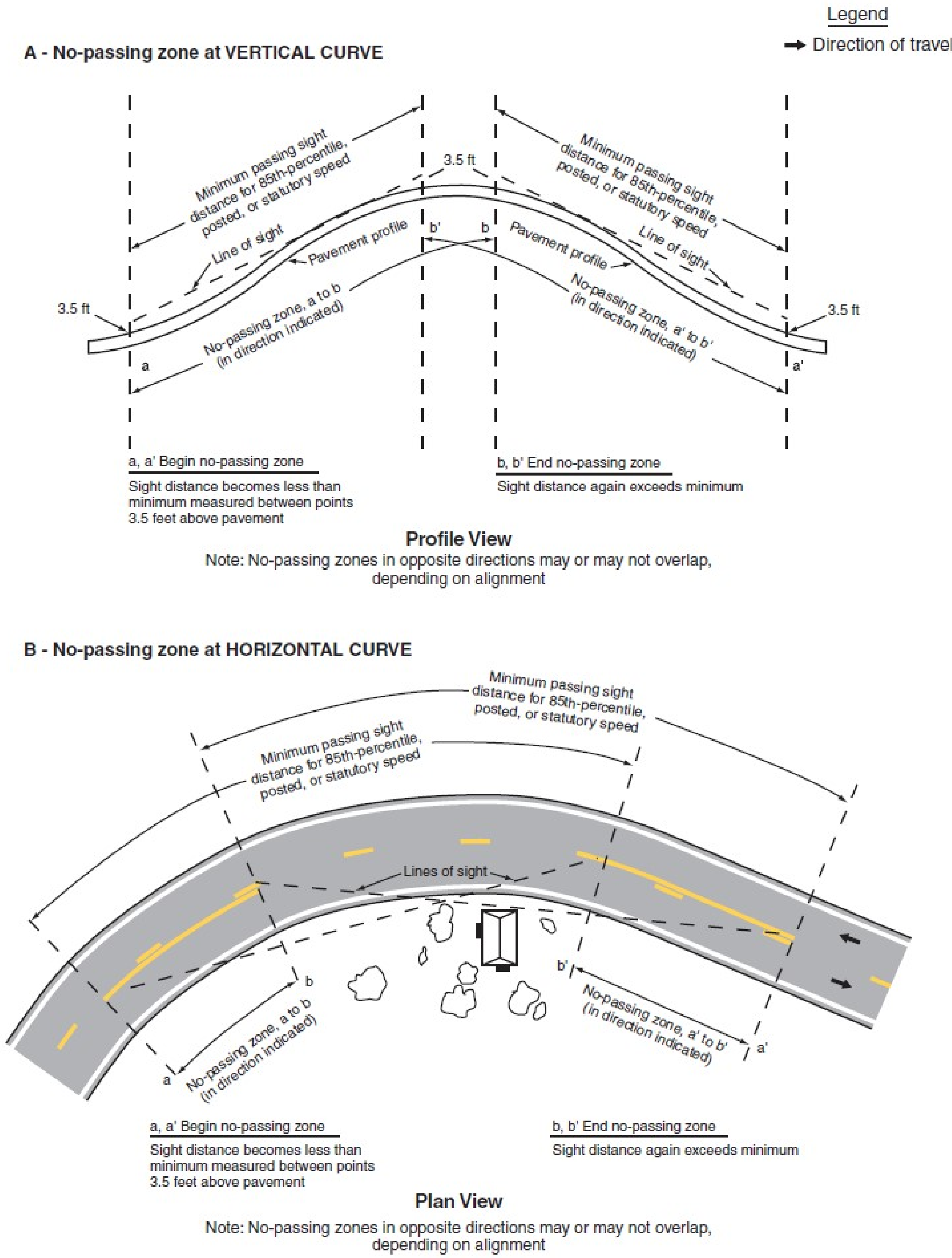
Passing sight distance is the length of roadway needed for drivers on two-lane two-way highways to pass slower vehicles without meeting opposing traffic.

Passing Sight Distance Definitions

Vertical Curve Distance where an object (3.5 ft above roadway surface) can be seen from a point 3.5 ft above the roadway

Horizontal Curve Distance measured (along center line or right-hand lane line for 3-lane roadway) between two points 3.5 ft above the roadway on a tangent line

Figure 3B-4. Method of Locating and Determining the Limits of No-Passing Zones at Curves



The following table shows design values for passing sight distance on two-lane highways. It has been shown that more sight distance is needed for passing maneuvers than for stopping sight distance which is continuously provided for along roadways.

Table 3-4. Passing Sight Distance for Design of Two-Lane Highways

Metric				U.S. Customary			
Design Speed (km/h)	Assumed Speeds (km/h)		Passing Sight Distance (m)	Design Speed (mph)	Assumed Speeds (mph)		Passing Sight Distance (ft)
	Passed Vehicle	Passing Vehicle			Passed Vehicle	Passing Vehicle	
30	11	30	120	20	8	20	400
40	21	40	140	25	13	25	450
50	31	50	160	30	18	30	500
60	41	60	180	35	23	35	550
70	51	70	210	40	28	40	600
80	61	80	245	45	33	45	700
90	71	90	280	50	38	50	800
100	81	100	320	55	43	55	900
110	91	110	355	60	48	60	1000
120	101	120	395	65	53	65	1100
130	111	130	440	70	58	70	1200
				75	63	75	1300
				80	68	80	1400

Source: AASHTO "Green Book" Table 3-4

Potential passing conflicts are ultimately determined by driver responses to:

- View of roadway ahead
- Passing and no-passing zone markings

Horizontal alignment is also crucial to determine the location, extent, and percentage of passing distances. More sight distance is required for passing maneuvers than for stopping sight distance which is continuously provided along roadways.

Minimum values for passing sight distances are based on Manual on Uniform Traffic Control Devices (MUTCD) warrants for no-passing zones on two-lane highways. These values are suitable for single or isolated passes only.

Driver Behavior Assumptions

- Passing and opposing vehicle speeds are equal to the roadway design speed
- Speed differential between passing and passed vehicle is 12 mph
- Passing vehicle has adequate acceleration capability to reach speed differential (40% of way through passing maneuver)
- Vehicle lengths are 19 feet
- Passing driver's perception-reaction time to abort passing maneuver is 1 second
- Deceleration rate of 11.2 ft/s^2 for passing vehicle when passing maneuver is aborted
- Space headway between passing and passed vehicles is 1 second
- Minimum clearance between passing and opposed vehicles upon return to normal lane is 1 second

Design passing sight values should also be based on a single passenger vehicle passing another single passenger vehicle.

Passing sight distances should be should be as long and frequent as possible, and equal or greater than the minimum values, depending on:

- **topography**
- **design speed**
- **cost**
- **intersection spacing**

While passing sections are used on most highways and selected streets, others can usually be provided at little or no additional cost.

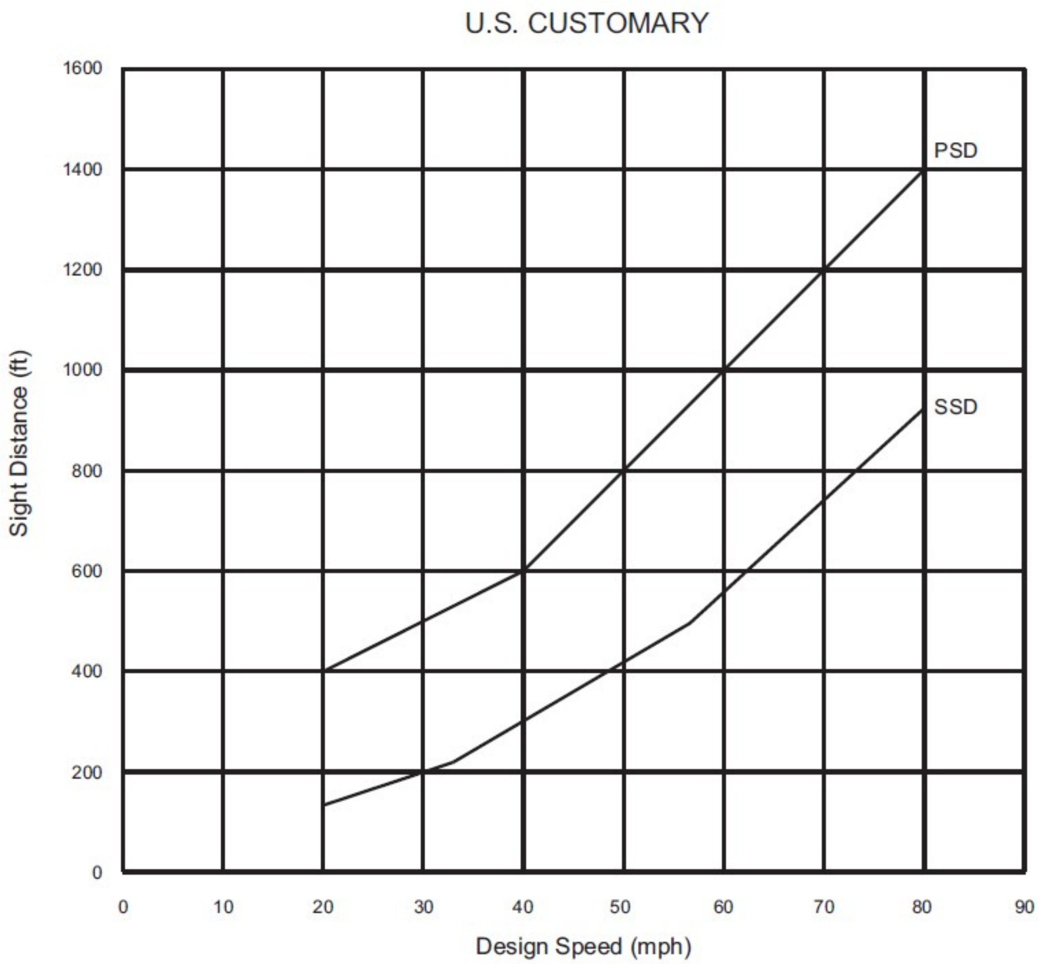


Figure 3-1. Comparison of Design Values for Passing Sight Distance and Stopping Sight Distance

Source: AASHTO “Green Book” Figure 3-1

Comparison of Sight Distance Design Values

Design Speed (mph)	Passing Sight Distance (ft)	Stopping Sight Distance (ft)
20	400	115
30	500	200
40	600	305
50	800	425
60	1000	570
70	1200	730
80	1400	910

INTERSECTION SIGHT DISTANCE

The potential for vehicular conflicts at intersections can be greatly reduced with proper sight distances and traffic control. Intersection efficiency depends on driver behavior – judgment, capability, and response. Approaching drivers need an unobstructed view of the intersection and approaching roadways to safely maneuver through the facility.

Intersection sight distance is the length of roadway along the intersecting road that the approaching vehicle should have to perceive and react to potential conflicts. Both roadway horizontal and vertical geometry can have a great effect on ISD.

Sight distance is needed to allow stopped vehicles a sufficient view of the intersecting roadway in order to enter or cross it. Intersection sight distances that exceed stopping sight distances along major roads are considered sufficient to anticipate and avoid conflicts. Intersection sight distance determination is based on many of the same principles as stopping sight distance.

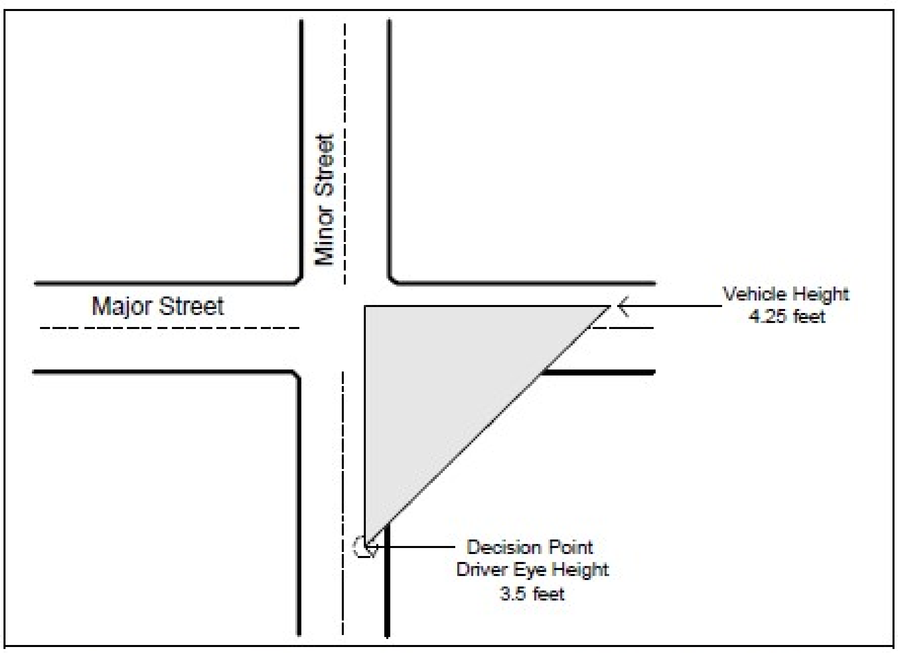


Figure 4.3. Heights Pertaining to Sight Triangles

Source: CTRE – Iowa State University

Clear sight triangles are areas along intersection approach legs that should be without any obstructions that could obscure any potential conflicts from the driver's view. For sight obstruction determination, the driver's eye is assumed to be **3.50 feet** above the road surface, and the visible object is **3.50 feet** above the intersecting road's surface. The dimensions are based on driver behavior, roadway design speeds, and type of traffic control. Object height is based on vehicle height of **4.35 feet** (15^{th} percentile of current passenger vehicle height minus an allowance of 10 inches).

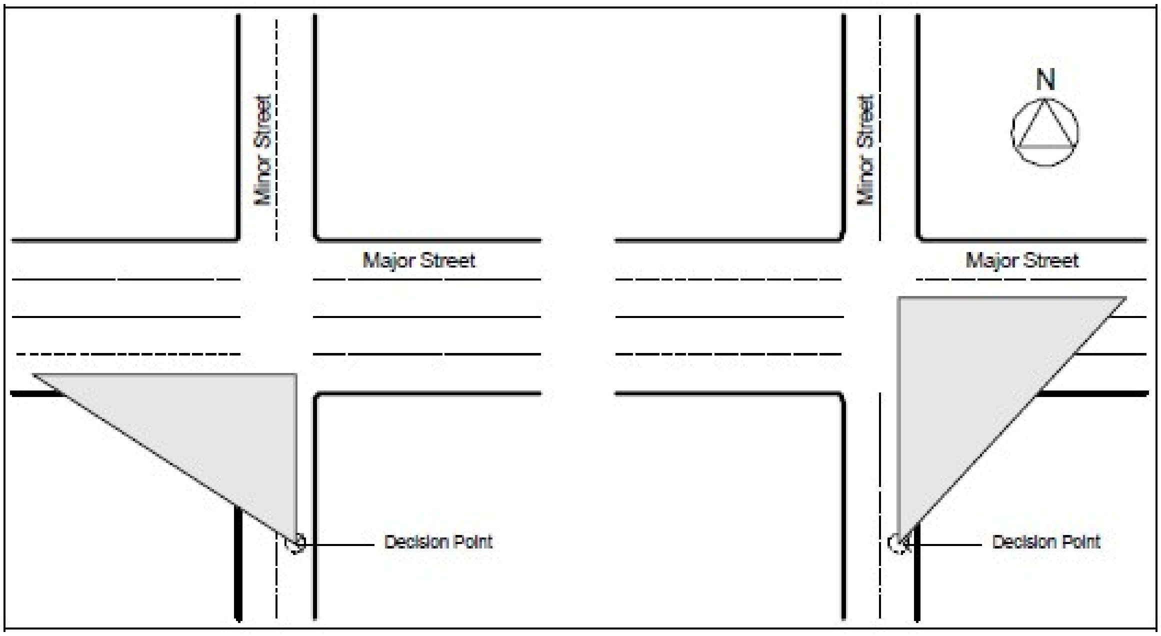


Figure 4.1. Approach Sight Triangles

Source: CTRE – Iowa State University

Approach sight triangles are triangular areas free of obstructions that could block approaching a motorist's view of potential conflicts. Lengths of the area legs should permit drivers to observe any potential conflicts and slow, stop, or avoid other vehicles within the intersection. These types of sight triangles are not needed for intersections controlled by stop signs or traffic signals.

Departure sight triangles provide adequate distance for stopped drivers on minor roads to depart the intersection and enter/cross the major road. These sight triangles are needed for quadrants of each intersection approach controlled by stop or yield conditions.

$$ISD = 1.47V_{major} + t_g$$

ISD = intersection sight distance (along major road) (feet)

V_{major} = design speed of major road (mph)

t_g = time gap for minor road vehicle to enter major road (seconds)

AASHTO's method for determining intersection sight distance is fairly complicated (speeds, traffic control, roadway cross-sections, obstruction location, vehicle types, maneuvers). Obstructions include building setbacks, trees, fences, etc. Railroad grade crossing sight distances to adjacent roadway intersections should also be addressed for intersection design and sight distance.

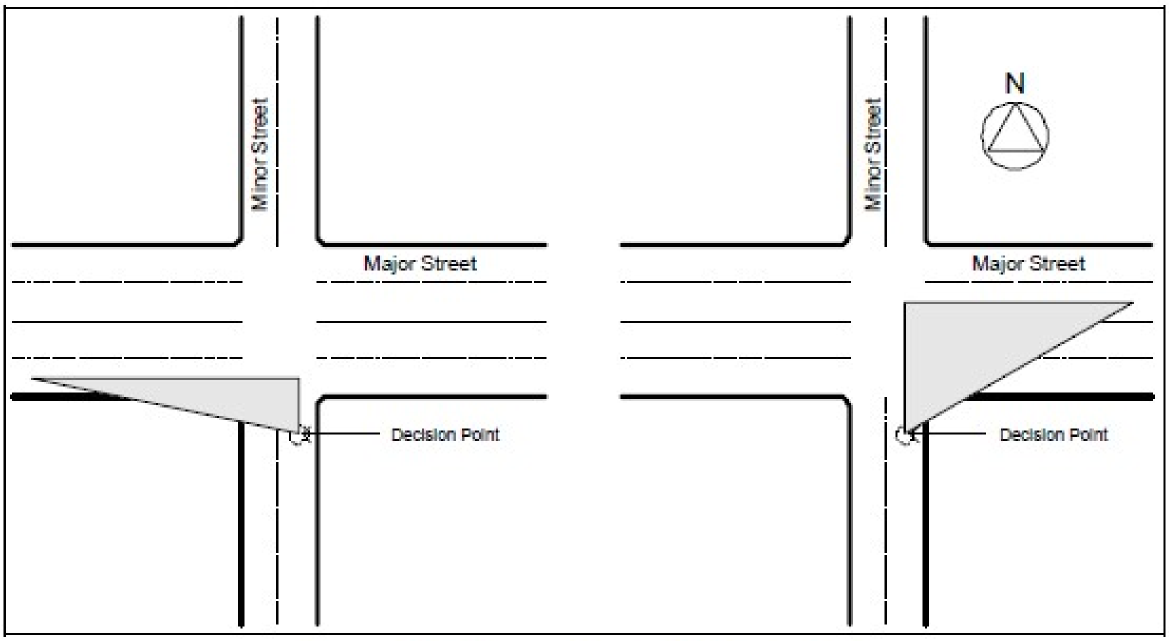


Figure 4.2. Departure Sight Triangles

Source: CTRE – Iowa State University

Methods for determining intersection sight distance vary according to the different types of traffic control:

- **Case A:** Intersections with no control
- **Case B:** Intersections with stop control on the minor road
  - **Case B1:** Left turn from the minor road
  - **Case B2:** Right turn from the minor road
  - **Case B3:** Crossing maneuver from the minor road
- **Case C:** Intersections with yield control on the minor road

- **Case C1:** Crossing maneuver from the minor road
- **Case C2:** Left or right turn from the minor road

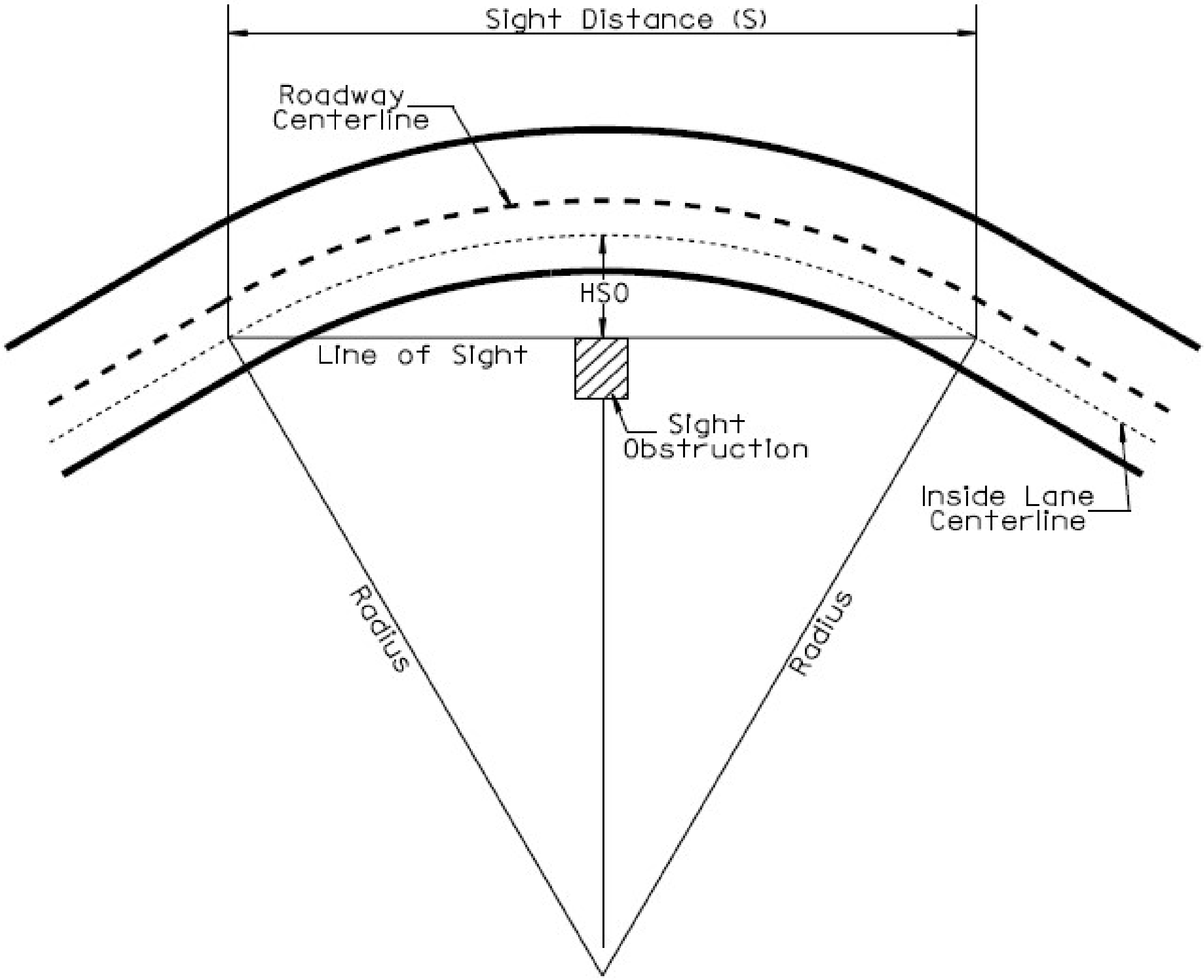
- **Case D:** Intersections with traffic signal control

- **Case E:** Intersections with all-way stop control

- **Case F:** Left turns from the major road

Sight distance across the inside of curves is a crucial design control for horizontal alignments. Due to various concerns (alignments, cross-sections, obstructions, etc.), specific study is needed for each curve and adjustments made to provide sufficient sight distance.

For **horizontal alignments**, the sight line is a chord of the curve as shown below. The stopping sight distance is along the centerline of the curve's inside lane.



Source: AASHTO "Green Book" Figure 3-23

AASHTO Equation 3-36 is suitable for circular curve lengths greater than the sight distance for the design speed.

$$HSO = R\left[1 - \cos\left(\frac{28.65S}{R}\right)\right]$$

HSO = horizontal sight line offset (feet)

R = radius of curve (feet)

S = stopping sight distance (feet)

Eye Height:	3.50 feet	
Object Height:	2.00 feet	Stopping sight distance
	2.75 feet	Midpoint of sight line where cut slope obstructs sight

The following alternatives may be considered where adequate stopping sight distance is not available:

- Increase offset to sight obstructions
- Increase curve radii
- Reduce design speed

Minimum passing sight distance values (two-lane road) are approximately twice those for the minimum stopping sight distance. Due to differences in sight line and stopping sight distance, design for passing sight distance should be limited to flat curves and tangents.

GENERAL CONTROLS

- **Any roadway alignment should be directional as possible.**

The horizontal alignment should be consistent with the topography and minimize any adverse impacts. Alignments consisting of short curves should be avoided since this may lead to erratic driving. Flowing centerlines that conform to the site's natural contours is generally preferable.

- **Avoid minimum radius values whenever possible.**

The central angle of all curves should be as small as practical to maximize roadway directionality. Typically, flat curves should be used with minimum radii for critical conditions.

- **Roadway alignment consistency is desirable.**

Sudden changes in the alignment should be avoided. For example, a series of successively sharp curves should be used to introduce a sharper curve.

- **Horizontal curves should be long enough for aesthetic purposes.**

These should avoid the appearance of a kink for small deflection angles. For a central angle of 5 degrees, curves should be a minimum of 500 feet long (with a minimum increase of 100 ft for each degree decrease in the central angle).

- **Avoid sharp curves on lengthy high embankments.**

The absence of other features (vegetation, cut slopes, etc.) makes it difficult for the driver to perceive and react to the extent of curvature.

- **Avoid changing median widths on tangent alignments.**

This will prevent distorted appearances.

- **Exercise caution when using compound circular curves.**

Compound curvature flexibility may tempt designers to use them without restraint. These curves should be avoided where curves are sharp.

- **Avoid sudden reversals in alignment.**

These changes make it difficult for safe operation (lane changes, etc.). Distances between reverse curves should be equal to the sum of the superelevation and tangent runout lengths, or an equivalent length for spiral curves.

- **Avoid "broken-back" or "flat-back" curve arrangements, where possible.**

These alignments containing a short tangent between two curves in the same direction usually violate operator expectations. Motorists generally do not expect successive curves in the same direction. Spiral transitions or compound curves are preferable for such situations.

- **Coordinate the horizontal alignment with the roadway profile.**

COORDINATION OF HORIZONTAL AND VERTICAL ALIGNMENTS

Geometric roadway design influences safety performance. Historical crash data has shown that roadway factors are the **second** most contributing factor to roadway accidents. Crashes are more likely to occur at locations with sudden changes in road character (i.e. sharp curves at the end of long tangent sections).

Design consistency compares adjacent road segments and identifies locations with changes that might violate driver expectations. This type of analysis can be used to show operating speed decreases at curves.

Horizontal and vertical geometrics are the most critical roadway design elements. These alignments should be designed concurrently to enhance

vehicle operation,

uniform speed,

and *aesthetics without additional costs.*

Examples include: checking for additional sight distance prior to major vertical alignment changes; or revising design elements to eliminate potential drainage problems.

Horizontal and vertical alignment geometric designs complement each other while poor designs can reduce the quality of both. It can be extremely difficult and costly to fix any vertical and/or horizontal deficiencies once a roadway is built. Any initial savings can be offset by economic losses due to crashes and delays.

Physical factors that help define roadway alignments include:

- Roadway traffic
- Topography
- Subsurface conditions
- Cultural development
- Roadway termini

Although design speed helps to determine the roadway's location, it assumes a greater role as the design of the horizontal and vertical alignments progress. Design speed aids in balancing all of the design elements by limiting many design values (curves, sight distance) and influencing others (width, clearance, maximum gradient).

GENERAL PROCEDURE

Coordinating horizontal and vertical alignments should begin with any roadway preliminary design. Any adjustments or corrections can be readily made at this phase.

Working drawings can be used for studying long, continuous plan and profile views to visualize the proposed three-dimensional roadway. Computer-aided drafting and design (CADD) systems are typically used to create optimal 3-D designs.

After development of a preliminary design, adjustments can be made for better coordination between the alignments. Using the design speed, the following factors should be checked:

Controlling curvature
Gradients
Sight distance
Superelevation runoff lengths

Also, the design controls for vertical and horizontal alignments should be considered, as well as all aspects of terrain, traffic, and appearance. All adjustments should be made before the costly and time-consuming preparation of construction plans.

For local roads, the alignment is impacted by existing or future development – with intersections and driveways being dominant controls. Designs should contain long, flowing alignments instead of a connected series of block-by-block sections.

AASHTO Design Guidelines for Horizontal and Vertical Alignments

- Vertical and horizontal elements should be balanced to optimize safety, capacity, operation, and aesthetics within the location's topography.

- Both horizontal and vertical alignment elements should be integrated to provide a pleasing facility for roadway traffic.

- Sharp horizontal curves near the top of a crest vertical curve or near the low point of a sag vertical curve should be avoided. Using higher design values (well above the minimum) for design speed can produce suitable designs and meet driver's expectations.

- Horizontal and vertical curves need to be as flat as possible for intersections with sight distance concerns.

- For divided roadways, it may be suitable to vary median widths for divided roadways. Independent horizontal/vertical alignments should be used for individual one-way roads.

- Horizontal and vertical alignments should be designed to minimize impact in residential areas. Typical applications include:

  depressed facilities (decreases facility visibility and noise)

  horizontal adjustments (increases buffer zones between traffic and neighborhoods).

- Geometric design elements should be used to enhance environmental features (parks, rivers, terrain, etc.). Roadways should enhance outstanding views or features instead of avoiding them where possible.

Exception: Long tangent sections for sufficient passing sight distance may be appropriate for two-lane roads needing passing sections at frequent intervals.

SUMMARY

Along with the roadway cross section (lanes and shoulders, curbs, medians, roadside slopes and ditches, sidewalks) and vertical alignment (grades and vertical curves), the **horizontal alignment** (tangents and curves) helps provide a three-dimensional roadway model. Its ultimate goal is to provide a safe, smooth-flowing facility that is crash-free. Roadway horizontal alignments are directly related to their operational quality and safety.

In today's environment, designers must do more than apply design standards and criteria to 'solve' a problem. They must understand how various roadway elements contribute to safety and facility operation, including the horizontal alignment.

This course is the second of two that summarizes the geometric design of horizontal alignments for modern roads and highways. This document is intended to serve as guidance and not as an absolute standard or rule. For further information, please refer to **AASHTO's A Policy on Geometric Design of Highways and Streets (Green Book)**. It is considered to be the primary guidance for U.S. roadway design. **Section 3.3 – Horizontal Alignment** was used exclusively to present fundamental horizontal roadway geometric design principles.

By completing this course, you should be familiar with the general design of horizontal roadway alignments. The objective of this course was to give engineers and designers an in-depth look at the principles to be considered when selecting and designing roads.

This course focused on the following:

Design Considerations
- *Cross slopes*
- *Radii*
- *Grades*

Traveled-way Widening
- *Design Methods*

Sight Distance
- *Stopping*
- *Decision*

Passing
Intersection

General Design Controls

Coordination of Horizontal & Vertical Curves

The fundamental objective of good geometric design will remain as it has always been – **to produce a roadway that is safe, efficient, reasonably economic and sensitive to conflicting concerns.**

REFERENCES

A Policy on Geometric Design of Highways and Streets, 6th Edition
AASHTO. Washington, D.C. 2011.

Note: *This text is the source for all equations, figures, and tables contained within this course, unless noted otherwise.*

Elementary Surveying, 6th Edition
Russell C. Brinker & Paul R. Wolf. Harper & Row. New York. 1977.

Handbook of Simplified Practice for Traffic Studies
Center for Transportation Research & Education – Iowa State. Ames, Iowa. 2002.

Low-Cost Treatments for Horizontal Curve Safety
Federal Highway Administration Office of Safety. Washington, D.C. 2006.

Manual on Uniform Traffic Control Devices (MUTCD)
Federal Highway Administration. Washington, D.C. 2009.

Standard Roadway Drawings
Tennessee Department of Transportation.

Traffic Engineering Handbook, 5th Edition
Institute of Transportation Engineers. Washington, D.C. 1999.