Roadway Vertical Alignments

An Online Continuing Education Course for Engineers

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Roadway Vertical Alignments

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INTRODUCTION

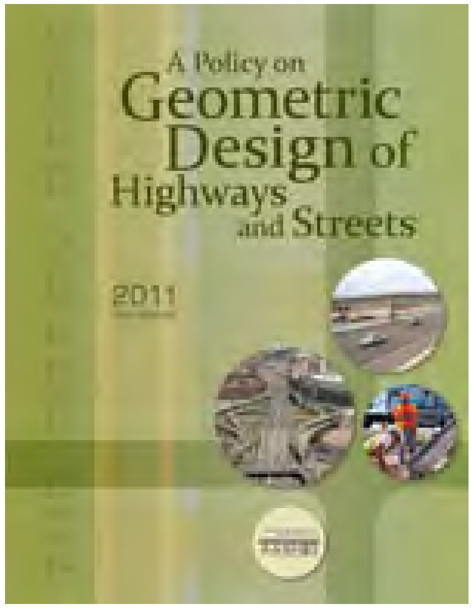
Roadway vertical alignments are a combination of various parabolic curves and connecting tangent grades. It is one of the fundamental three-dimensional road features directly related to safety, operations, drainage, and construction requirements. Together with the horizontal alignment (tangents and curves) and roadway cross-sections (lanes, shoulders, curbs, medians, roadside slopes, ditches, sidewalks), the vertical alignment (grades and vertical curves) help provide a three-dimensional roadway layout.

This course focuses on the geometric design of **vertical 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 vertical roadway alignments. The course objective is to give engineers and designers an in-depth look at the principles to be considered when designing vertical alignments.

Subjects covered include:

- Sight Distance
    - Stopping
    - Decision
    - Passing
    - Intersection
- Vertical Alignment
    - Grades
    - Climbing lanes
    - Passing opportunities
    - Emergency escape ramps
- Vertical Curves
    - Sag
    - Crest
- 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 3.4 Vertical 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.**

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.

<u>Sight Distance Criteria</u>

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 90th 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).

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

SSD = stopping sight distance (feet)
V = design speed (mph)
a = deceleration rate (ft/sec^2)
t = brake reaction time (2.5 seconds)

Stopping Sight Distance - Level Roadways

Design Speed (mph)	Brake Reaction Distance (ft)	Braking Distance (ft)	Stopping Sight Distance	
			Calculated (ft)	Design (ft)
20	73.5	38.4	111.9	115
30	110.3	86.4	196.7	200
40	147.0	153.6	300.6	305
50	183.8	240.0	423.8	425
60	220.5	345.5	566.0	570
70	257.3	470.3	727.6	730
80	294.0	614.3	908.3	910

Table 3-1 (*Source: AASHTO "Green Book")*

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)

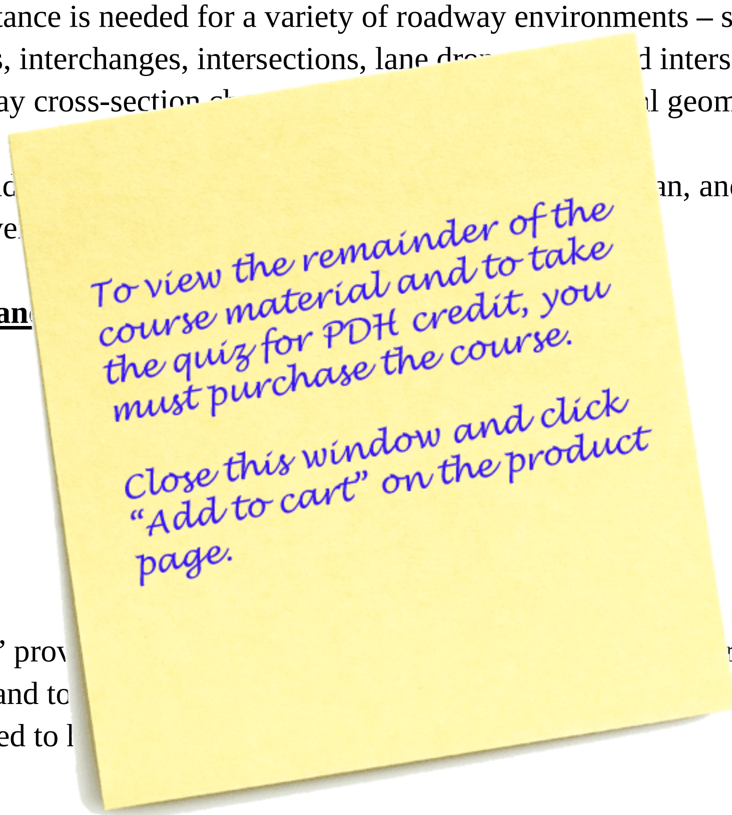
Certain situations requiring complex decisions or maneuvers (unexpected conflicts, navigational needs, roadway changes, etc.) can place extra demands on drivers. These circumstances usually require longer sight distances than those for stopping.

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 dr... d intersections, median crossovers, roadway cross-section c... l geometric configurations.



DSD values depend... an, and the type of avoidance maneuve...

Avoidance Man...		Time (sec)
A		3.0
B		9.1
C		10.2 to 11.2
D		12.1 to 12.9
E		14.0 to 14.5

The "Green Book" prov... opriate values for critical locations, and to... t distances. Critical decision points need to l...