Introduction to Roadway Geometrics

An Online Continuing Education Course for Engineers

Course Number: T-4015

Credit: 4 Hours / 4 PDH / 4 CPD

Introduction to Roadway Geometrics

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Introduction

Every road user is impacted by roadway geometrics each time they travel. Knowing the principles of geometric design will enable you to understand how and why transportation professionals make decisions regarding the path of a road, street, or highway as it travels from one point to another. An understanding of the constraints imposed on designers by the existing site conditions of the location where a road project is being considered, the impacts of standards set by regulatory agencies, and the need to provide a consistently safe environment for roadway users is key for everyone involved in the planning and design of transportation infrastructure.

After completing this course you will be familiar with current design practices in each major aspect of roadway geometrics. This includes sight distance, where the designer ensures drivers can see far enough along the road in front of them to react to hazards, pass slower vehicles, or decide how to respond in complicated situations requiring extra time for thought and execution. Also covered are the ways to change the horizontal direction of the road by introducing curves into its alignment. Part of the discussion of horizontal curves will cover sharp curves that require the roadway to be banked (also known as superelevation) to assist drivers in maintaining their lane position and speed while traveling through the curve. The last major topic is configuring the vertical course of a road. This includes how steep a road should be, and how curves are designed for the vertical alignment of a road to provide safe and comfortable travel.

Minor topics that accompany the larger portions of this course include the coordination of the horizontal and vertical geometry of a road with each other, with the drainage system for the road, and with existing and proposed obstructions.

Although the formulae, speeds, and other design criteria discussed in this course vary with the rules and laws of each locale, many are based off of the policies of the American Association of State Highway and Transportation Officials (AASHTO). This has resulted in a fairly uniform approach to the design of new roads and the reconstruction of old ones, and this course will cover AASHTO policies. Measurements and equations in this course are given in U.S. Customary units only.

Rules and Regulations

Many of the components of roadway design, are governed by the rules that regulatory agencies, usually one or more different levels of government, have set for different types of roads. These rules must be thoroughly reviewed by engineers because they control the input variables used throughout the geometric design process.

One of the most frequent distinctions between types of roads is whether they are classified as urban or rural. In general, urban streets experience conditions with slower-moving vehicles and are not required to accommodate large vehicles such as trucks as easily as rural locations. These requirements reflect the reality of urban streets as busy routes with frequent stops, often with parking lanes, bicycles lanes, and other elements that interrupt the flow of traffic. Rural roads are more likely to have higher speeds, fewer lanes, and significantly fewer intersections.

It is important to note that rural roads do not necessarily handle less traffic than urban streets. A rural highway may be a major truck route or the only easy connection between two separate urban areas. Urban streets may only serve a neighborhood or carry only local commercial traffic. The type and volume of traffic using a road, quantified as the *Average Daily Traffic (ADT)*, can vary to such an extent that the amount of traffic expected to use a road rarely controls the geometric design. Very low volume locations, where ADT $\leq$ 400, may be designed to less rigorous standards depending on the guidelines set by the regulatory agency.

Within a given urban or rural area, some roads handle more traffic than others. Some also handle traffic more efficiently than others, known as the *Level of Service*. Another variable in roadway conditions is access control, which is the practice of limiting or prohibiting the ability of drivers and the general public to access the road. An example of access control is allowing fewer intersections along a road. An increase in access control increases travel speed for motorists.

A three tier hierarchy, known as *Functional Classification*, exists to identify roads based on their relative importance to the transportation network and how well they allow traffic to flow. *Arterials* are defined as providing a high level of service at high speed for long distances with some access control. *Collectors* have a lower level of service, provided at a lower speed, and over a shorter distance than arterials, because collectors gather traffic from local roads, requiring there be little to no access control along a collector. *Local Roads* are all other roads, and their primary purpose is to provide property access with little regard to through movement of vehicles along the local road network.

The topography of the land through which a road travels also impacts the design. As the terrain becomes steeper, it is harder to provide a smooth, easy ride. Some requirements, such as maximum grades, are relaxed in steeper locations. For planning purposes, terrain is classified as one of three types. Flat locations have gentle grades and changes in grade occur gradually. Rolling areas have moderate grades and grade changes more rapidly and frequently. Mountainous areas are steep with quick and frequent grade changes. Terrain classification also plays a role in the capacity analysis to determine the level of service for major roads and highways.

Far and away the most important variable in roadway geometrics is the *Design Speed*, which is the vehicular speed assumed by engineers during design. Different design speeds are set for different locations with the following considerations:

1. Functional Classification – higher classifications have a higher design speed. For example, an arterial will have a higher design speed than a collector.
2. Urban or Rural – Rural locations usually have a higher design speed than urban areas.
3. Terrain – Flatter land has a higher design speed than rolling or mountainous areas.
4. Traffic Volume – As discussed above, very low ADT roads may be allowed to provide a less comfortable ride and lower level of service than other roads.

The relationship between the components controlling the design speed is shown in Figure 1 below.

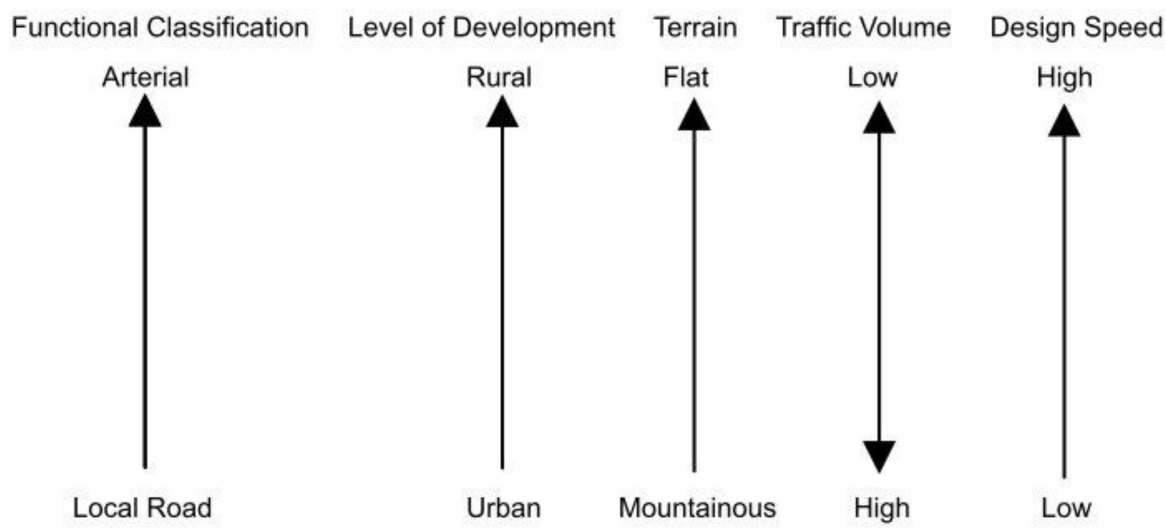


Figure 1: Design Speed Controls

Overall, the criteria used to set the design speed reflect the need for a cost effective transportation system. Busier roads must accommodate more traffic at a higher level of service. Less-used streets can be designed to a lower standard because fewer people are affected. When it comes to the mathematics of roadway geometrics, raising or lowering the design speed is how engineers can best impact the level of service. Other factors, such as the number of lanes, lane widths, or the presence of traffic control such as traffic signals or signs can all impact the level of service. Each of these elements is intended to improve the function of a road to allow traffic to flow at the highest safe speed, in order to move people as quickly and efficiently as possible. The highest safe speed will never exceed the design speed, above which motorists may have trouble controlling their vehicle as they drive. Many factors, such as heavy traffic, snow, rain, ice, construction operations, traveling at night, etc., can reduce the highest safe speed below the design speed.

Other design controls such as providing larger pavement widths for trucks at intersections to accommodate their larger turning radii, considering bicyclists and pedestrians, and when to provide safety systems such as traffic barrier or guardrail are all important to the overall design of a road. These topics are beyond the scope of this introductory course.

Sight Distance
Roadway design must always provide drivers with clear sight lines to see far enough along the road to have time to react to unexpected or complicated conditions ahead of them. The length along the road alignment required to be visible to a motorist traveling at the design speed, the *Sight Distance*, varies depending on the situation a driver is expected to encounter at a given location.

Stopping Sight Distance
At a minimum, geometric design must always provide *Stopping Sight Distance*. This is the distance required for a driver to notice an obstruction on the road ahead, react to the obstruction and begin braking, and slow the vehicle to a stop. Stopping sight distance increases when traveling downhill because gravity acts against the driver. It also increases when the traction between the tires and the pavement decreases, such as during a rainstorm; for this reason typical friction values are given assuming wet pavement and old, worn tires. A vehicle's deceleration rate in a given set of conditions can be used in lieu of a friction value.

A diagram of stopping sight distance is shown in Figure 2 below.

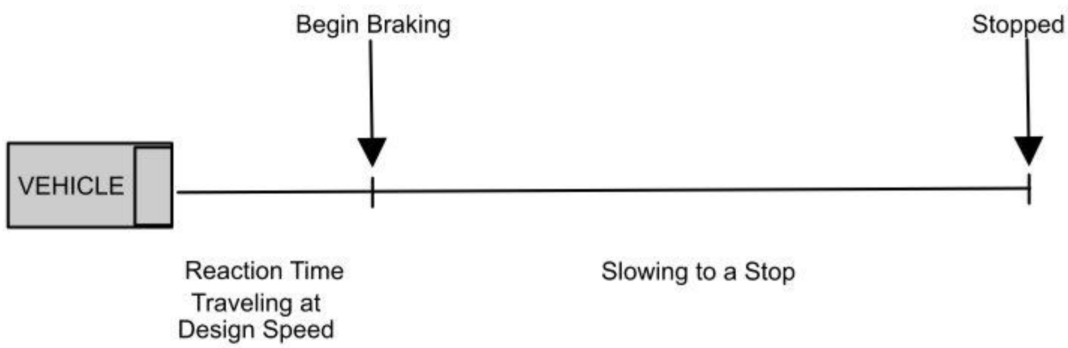


Figure 2: Stopping Sight Distance

Stopping sight distance is calculated according to the following equation:

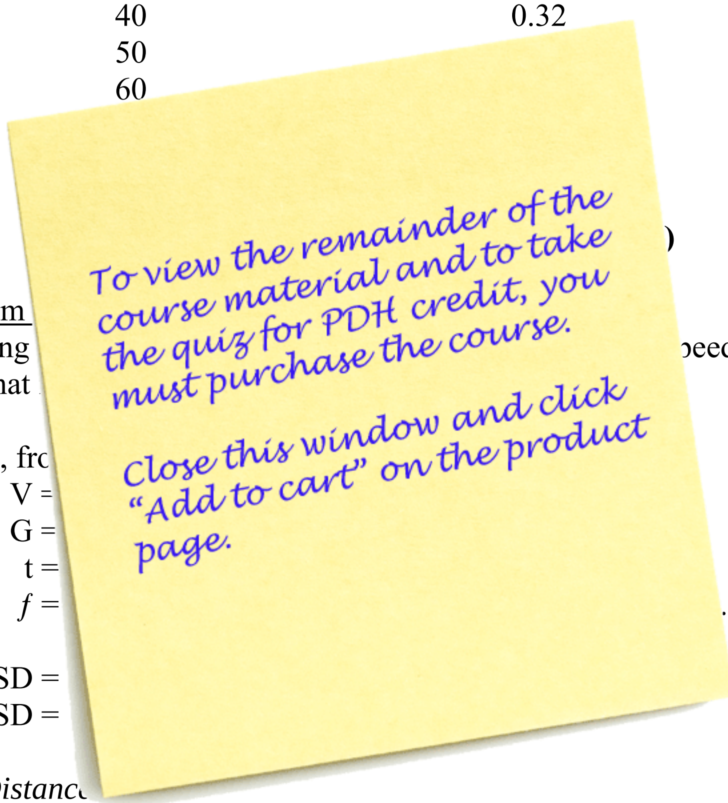
$$SSD = (1.47)(V)(t) + V^2/[30(f+G)] \qquad \text{(Equation 1)}$$

Where:
SSD = Stopping Sight Distance (ft)
V = Velocity of the vehicle (mph)
t = Reaction time (seconds), default = 2.5 seconds
f = coefficient of friction between vehicle and road
f = a / g, where:
a = deceleration rate (ft/sec^2), default = 11.2 ft/sec^2
g = acceleration due to gravity, 32.2 ft/sec^2

G = Road grade (ft/ft), negative for downhill

Typical friction factors for passenger cars are shown in Table 1 below and apply to wet conditions on any type of pavement. Note that various studies have produced widely different friction factors for similar situations. If you plan to use f directly (instead of a/g), a good source for appropriate f values for your location is the state Department of Transportation.

Design Speed (mph)	Coefficient of Friction, f
20	0.40
30	0.35
40	0.32
50	
60	



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Example Problem

You are designing ... peed of 60 mph on a 5.0% downgrade. What

Solution, frc

V =

G =

t =

f = .35

SSD =

SSD =

Passing Sight Distanc

On two-lane, two-way roads, designers must also consider providing *Passing Sight Distance*. This is the length along the roadway a driver needs to safely execute a passing maneuver by moving into the opposing lane, passing the slower vehicle, and returning to the correct lane without colliding with an opposing vehicle that appears once the passing maneuver has begun. Passing sight distance is usually provided only in locations where both the horizontal and vertical alignments are along tangents (straight lines without curves) and the vertical alignment is relatively flat. Incorporating passing into horizontal or vertical curves requires larger curves which may not be cost-effective.

A two-part diagram of passing sight distance on a tangent section is shown in Figure 3 and Figure 4 below. Figure 3 is the first portion of the maneuver, when the passing vehicle changes lane and prepares to pass.