CHAPTER 5. GEOMETRIC ANALYSIS

Site Geometric Characteristics and Coverage Area Identification

This chapter aims at analyzing the geometric aspects and characteristics of passing problem on two-lane vertical curve. It aims also at defining the limits of the area to be put under surveillance. The analysis relies mainly on the approach specified in the AASHTO "green book".

5.1 Stopping Sight Distance

The stopping distance on a grade is a function of a number of factors including the driver's perception-reaction time, the vehicle speed, the friction between the vehicle's tires and the road surface, and the grade level. The stopping distance "d" is computed using equation:

$$d = vt + \frac{v^2}{2g(f \pm G)}$$

Where:

v = average speed of passing vehicle(m/sec) ;

t = perception-reaction time (seconds)

f = friction coefficient (unitless)

g = gravity constant (m/sec-sq.))

G = road grade expressed in percent divided by 100. (Positive for upgrade and negative for downgrade).

Referring to AASHTO 1990, for a an average 2.5 perception-reaction time (this point will be more elaborated when addressing the human factors in the simulation task), and using Imperial units, the equation could be reformulated as follows:

$$d = 3.67v + \frac{v^2}{30(f \pm G)}$$ where d is expressed in feet and v in miles per hour.

Since the design speed on this section of Rt.114 is 55 mph, the oncoming car speed is assumed to be 55 mph, and the passing car speed is applied as 60 mph. The oncoming

car, and the violator car will be on either side of the vertical curve, otherwise they would fall in the field of sight of each other and the violator would not attempt an overtake maneuver.

Assuming the friction coefficient (f) is based on the wet road surface conditions, and applied as 0.28, the required stopping distances for emergency stopping (car coming on opposite direction) can be determined as follows:

Case 1:

For the conforming car traveling at 55 mph, on average 2.1% slope upgrade (westbound), the stopping distance = 537 ft, and for the violating car traveling at 60 mph, on the other 4.2% slope upgrade (eastbound), the stopping distance = 593 ft.

Total distance required to stop without having a crash = 1130 ft.

Case2:

For the conforming car traveling at 55 mph, on 4.2% slope upgrade (eastbound), the stopping distance = 515 ft, and For the violating car traveling at 60 mph, on average 2.1% upgrade slope (westbound), stopping distance = 619 ft.

Total distance required to stop without having a collision = 1134 ft.

The total stopping distance given above should be considered as the danger stopping distance, which will barely prevent a head-on collision of the two opposing cars. The minimum length for the definition of blind spot on this vertical curve will be applied as 1150 ft.

5.2 Passing Sight Distance as determined by AASHTO

The minimum passing sight distance value is important in determining whether there is enough space to complete a normal safe passing maneuver. This distance has to be examined in order to establish the correct boundaries of the danger zone. While there may be occasions to consider multiple passings, where two or more vehicles pass or are

passed, AASHTO did not find practical to assume such conditions in developing the minimum design criteria.

The minimum passing sight distance for two-lane highways is determined as the sum of the four distances (see Figure 5-1 below).

d_1 – Distance traversed during perception and reaction time and during the initial acceleration to the point of encroachment on the left lane.

d_2 – Distance traveled while the passing vehicle occupies the left lane.

d_3 – Distance between the passing vehicle at the end of its maneuver and the opposing vehicle.

d_4 – Distance traversed by an opposing vehicle for two-thirds of the time the passing vehicle occupies the left lane, or 2/3 of d2 above.

- The distance d1 traveled during the initial maneuver period is computed as follows:

$$d_1 = 1.47t_1(v - m + \frac{at_1}{2})$$

where:

t1 = time of initial maneuver (seconds);
a = average acceleration (mph/sec);
v = average speed of passing vehicle (mph);
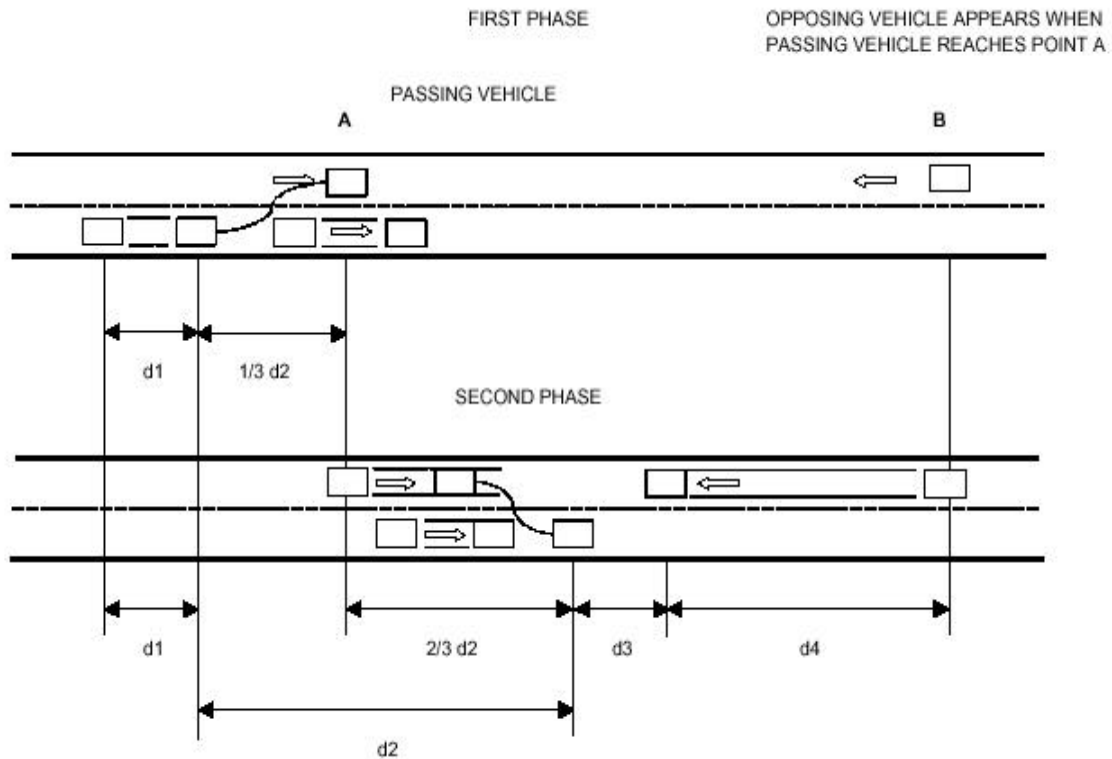m = difference in speed of passed vehicle and passing vehicle (mph).

- The distance d2 traveled in the left lane by the passing vehicle is computed by the following formula:

$$d_2 = 1.47vt_2$$

where:

t2 = time passing vehicle occupies the left lane (seconds);

v = average speed of passing vehicle (mph).

Figure 5-1. Breakdown of Passing Distance (*Source: AASHTO*)

- Clearance length (d3)**.** The clearance length between opposing vehicle and passing vehicle at the end of the maneuvers usually varies from 110 to 300 ft. **For our simulation, the accident occurs at d3 much less the assumed 250 feet length adopted by AASHTO for the 50-60 mph speed group.**

- Distance traveled by opposing vehicle (d4)**.** Passing sight distance includes the distance traversed by an opposing vehicle during the passing maneuver to minimize the chance of passing vehicle meeting an opposing vehicle while in the left lane. The opposing vehicle is assumed to be traveling at the same speed as the passing vehicle, so d4 = 2 d2 / 3.

In the project site, and for speeds ranging from 50 – 60 mph, the total required safe passing distance (i.e. d1+ d2 + d3 + d4) is approximately 1915 feet.

However, the sight distances required to permit vehicles traveling up-grade to pass safely are greater than those required on level roads because reduced acceleration of passing vehicle, which increases the time of passing. If passing is to be performed safely on up-grades, the passing sight distance should be greater than the AASHTO derived minimum. Accordingly, passing sight distance would fall between 1915 ft and 2300 ft of clear sight. The design value for minimum passing sight distance of two-lane highway proposed by AASHTO for our speed group is 2100 feet. Unfortunately, the vertical curve length studied in this project is much shorter than the required for safe passing distance as we will see next.

5.2.1 Crest Vertical Curves

Under this section we are going to examine the minimum lengths of crest vertical curve (L) as determined by sight distance requirements (D). The basic formulas for length of parabolic vertical curve in terms of algebraic difference in grade and in sight distance follow (as provided by AASHTO):

When S<L $\rightarrow L = \dfrac{AD^2}{200(\sqrt{h_1} + \sqrt{h_2})^2}$ or, when S>L $\rightarrow L = 2D - \dfrac{200(\sqrt{h_1} + \sqrt{h_2})^2}{A}$

Figures (5-2 a, b) illustrate the vertical curve components for both cases.

Where: L = length of vertical curve, ft;

D = sight distance, ft;

A = algebraic difference in grades, percent;

h_1 = height of object above roadway surface, ft.

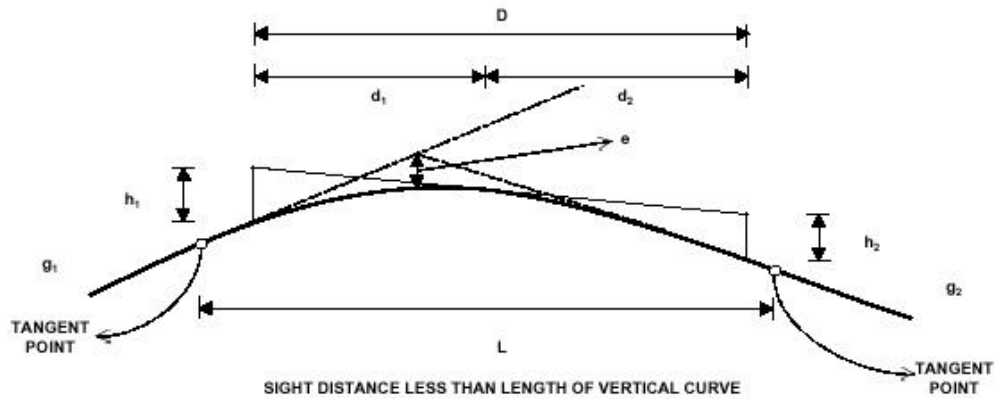h_2 = height of object above roadway surface, ft.

Figure 5-2a. Vertical Crest Components For S<L

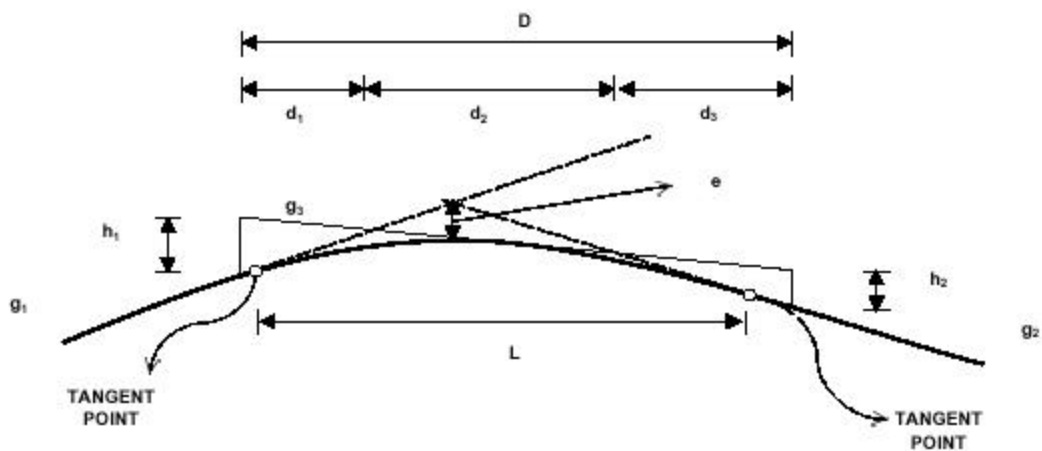**Figure 5-2b Vertical Crest Components For S>L**

Assuming the height of driver eye is 3.5 feet and the height of opposing car is 4.25 feet, the general formulas become:

When S< L $\rightarrow L = \dfrac{AD^2}{3093}$ or, when S>L $\rightarrow L = 2D - \dfrac{3093}{A}$

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For our case where A = 8.4 %, the minimum vertical crest required for stopping sight distance of 1150 will be:

$$L = 2 \times 1150 - \frac{3093}{8.4} = 1932 \text{ ft} >> \text{the length of the existing vertical crest of 850 feet.}$$

This length shortage explains the lack of visibility caused by the road profile leading to crashes when reckless and aggressive drivers try to make illegal passing maneuvers at that stretch of road.

5.3 Surveillance Area

With reference to the geometric properties of the vertical curve, and the emergency stopping distance of 1150 ft., visibility and danger zone limits are geometrically examined. The danger zone should be between the limits in which one driver will attempt an overtake maneuver, without having a clear sight of opposite traffic and enough stopping distance. Therefore, the critical 1150-ft. emergency stopping distance should be "under-the-sight" in each crest side, if the vehicles are to avoid having a collision.
For the east side of the vertical curve and depending on the geometry of road, the boundary of the "visible" 1150 feet stopping distance falls at mile point of 114 (Figure 5-3). Similarly, the boundary in the west side falls at the mile point of 135.5 (Figure 5-4).
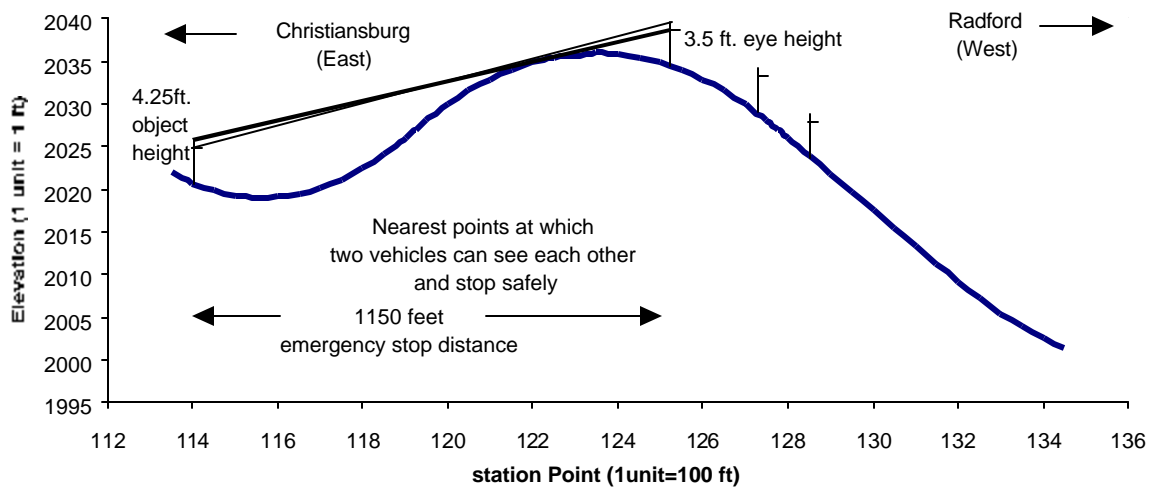

Figure 5-3. The East Side Boundary Of The Danger Zone
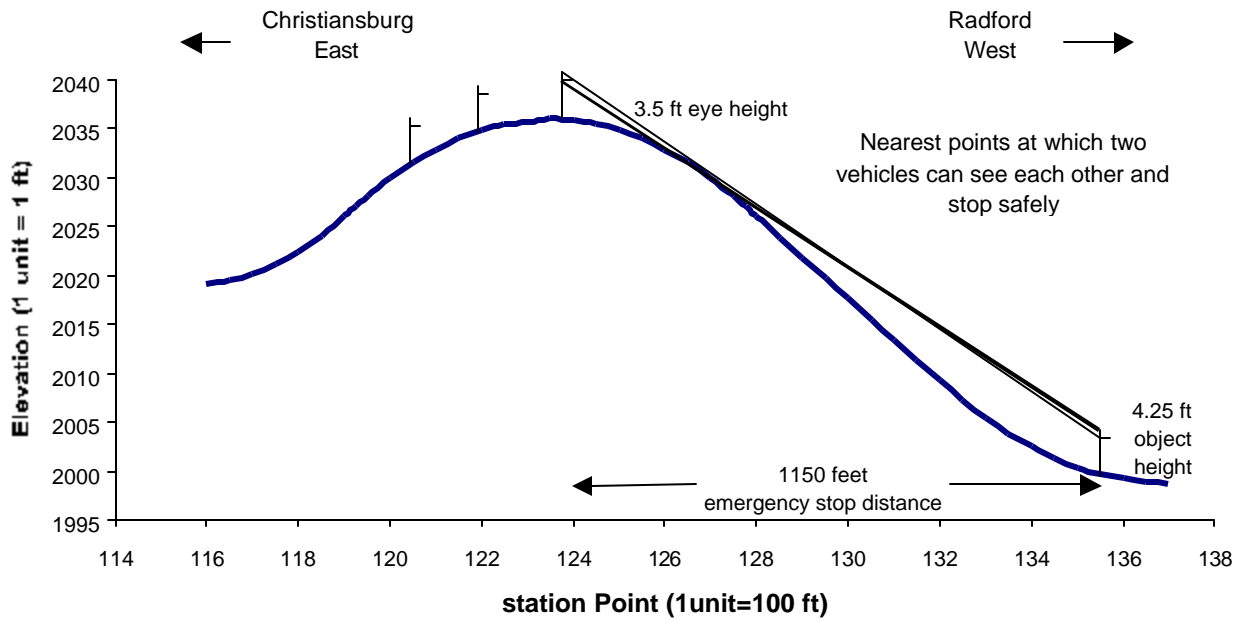
Figure 5-4. The West Side Boundary Of The Danger Zone

Based on the above geometric analyses, this danger zone can be described as the area in which no lane changes should be taken place, at any time. The total length of this zone is about 2150 ft (the two areas are overlapping) extending from mile point 114 to mile point 135.5. Figure 5-5 below delineates the wide danger area that should receive surveillance and be covered by the detection system.
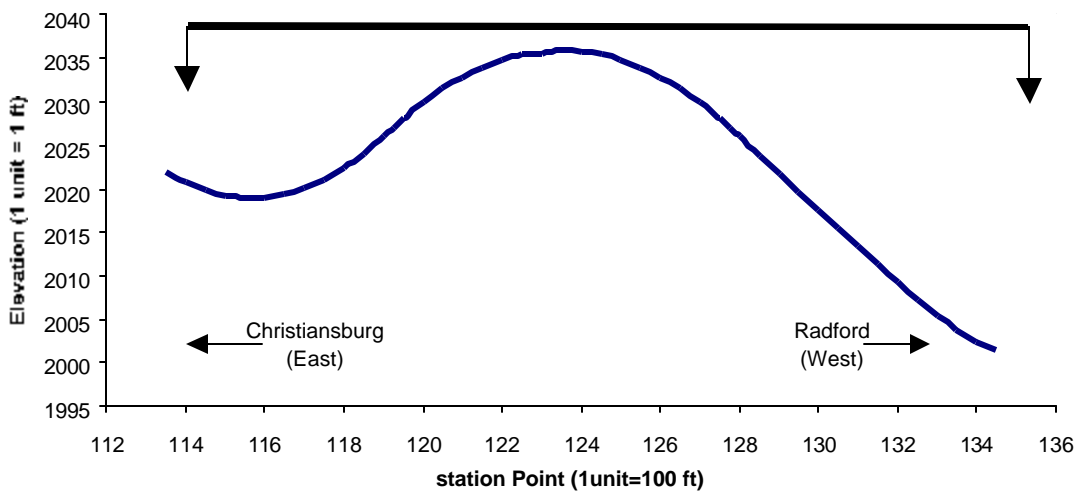

Figure 5-5. Danger Zone Receiving Surveillance

5.4 The blind spots

Based on the curve geometry and the assumptions about the speeds and vehicles type (the heights of the driver eye is 3.5 feet, and of the opposing vehicle is 4.25 feet), we may distinguish two blind spots in which the drivers in the two opposing vehicles cannot see each other (figure 5-6). The two blind spots extend in our case between mile points 114 and 122 in the east side of the curve, and between mile points 126 and 135.5 in the west side. A car in the middle 400 feet between the two blind spots can see part of the curvature but may not long enough to make a safe full stop.
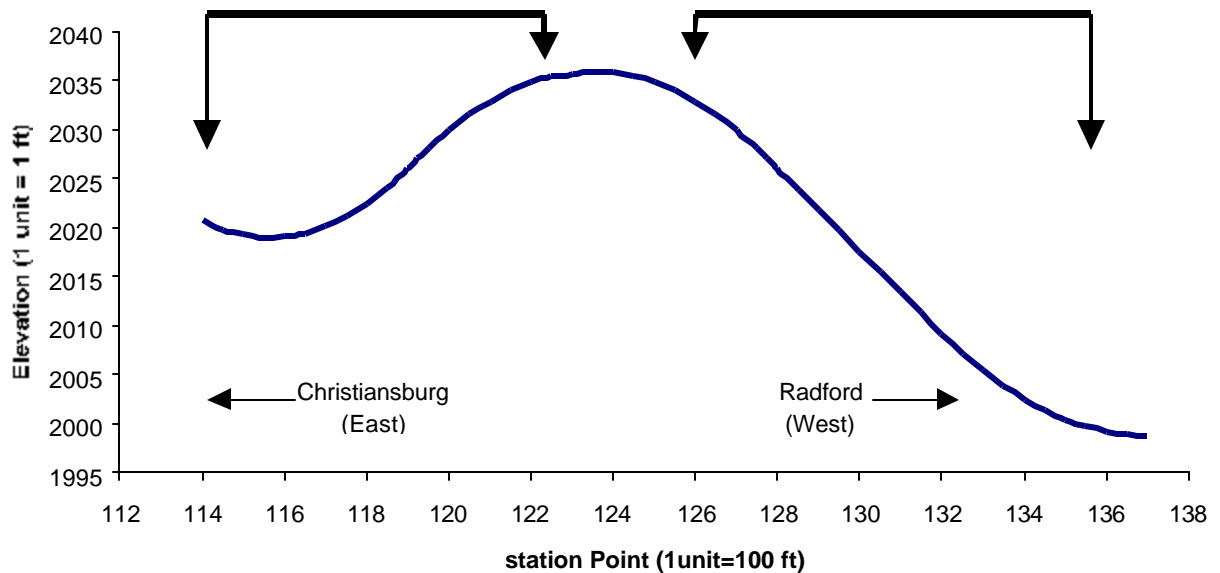
Figure 5-6 The Limits Of The Blind Spots

The significance of blind spots concept arises from the important role it plays when simulating the illegal passing maneuver because since the drivers of violating car and opposing cars are not able to see each other they will continue their path at their speed and get closer to each other until arriving to one of two possibilities:

1- One of drivers will reach the point where he or she can have a full capability to see the other side of the curve or,

2- Both drivers reach the middle area where they can have a partial view to the other side (not the whole other side) but eventually the will see each other.

In these two cases, one or both drivers will start reacting to avoid the collision.

Finally, It should be noted here that the boundaries specified in our geometric analysis is not a static photo shot because it is based on assumptions about predefined fixed values of speeds, friction coefficient, perception-reaction time, the heights of driver eye and opposing vehicles, etc. In reality all these parameters reveal more complexity and ought to be treated as variables that may differ depending on the driver behavior, pavement condition and vehicles type and conditions. Anyway, this issue will be dealt with in the simulation chapter in a more detailed way.