Road Design Fundamentals

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Executive Summary

The objective of the following report is to summarize the knowledge that I gleaned this past summer while serving as an intern with the Iowa Department of Transportation through the Summer Transportation Internship Program for Diverse Groups (STIPDG) and share with my fellow interns some basic geometric principles in road design. Subjects covered in the following report include: vertical curve fundamentals, stopping sight distances, horizontal curve fundamentals, vehicle cornering, and cross sections. Furthermore, this report gives a real life example of a side road entrance that is being relocated for a highway project that utilizes these concepts and that illustrates the technology and computer aided design that transportation engineers employ in the design process.
I.) Introduction

Virtually every aspect of the U.S. economy and way of life is tied directly or indirectly to highways. From the movement of freight and people to the impact on residential, commercial, and industrial locations, highways have had, and continue to have, a profound effect on American society. Highway engineers must strive toward two goals: 1.) Providing a high level of service (i.e. seeking to minimize travel times and delays) and 2.) Providing a high level of safety. The two goals are not only often contradictory (e.g., higher speeds minimize travel times but may also decrease safety), but must be achieved in the context of ever-changing constraints. Such constraints can be broadly classified as economic (the cost of highway-related projects), political (the community-related impacts of projects), and environmental (the impact of projects on the environment measured in terms of air, water, and noise impacts, and quality of life).

The following report will summarize some road design basics, as well as provide a real life example, shown in Figure 1, of a side road entrance that is being relocated for a highway project that will utilize these concepts.

Figure 1. Plan view example
2.) Road Design

The alignment of a highway is a three-dimensional element, designed in x, y, and z coordinates illustrated in Figure 2. However, in highway design practice, three-dimensional design computations are cumbersome and, what is perhaps more important, the actual implementation and construction of a design based on three-dimensional coordinates has traditionally been prohibitively difficult. (Although, contractors have begun using GPS technology utilizing 3-D surface files to construct jobs.) As a consequence, the three-dimensional highway alignment is reduced to two two-dimensional alignment problems, as illustrated in Fig. 3. Furthermore, distance is measured along the centerline of the highway in terms of stations, with each station consisting of 100ft of highway alignment distance.

Figure 2. Highway alignment in three-dimensions
2.1) Vertical Curve Fundamentals:

Changes in existing terrain and differential between connecting road grades require the construction of vertical curves. Construction of a vertical curve is generally a costly operation requiring the movement of significant amounts of earthen material. Thus one of the primary challenges facing highway designers is to minimize construction costs by maximizing the earth cut and fill balance and keeping the length of the vertical curve to a minimum while still providing an adequate level of safety. An appropriate level of safety is usually defined as the level of safety that provides drivers with significant sight distance to allow them to safely stop their vehicles to avoid collisions with objects obstructing their forward motion. Computation of this necessary stopping sight distance (SSD) can be found by the following equation: (AASHTO 128)

\[
SSD = \frac{V_1^2}{2g(f \pm G)} + V_1 t_p
\]

Equation 2.1.1
Where SSD is the stopping sight distance, $V_1$ is the initial vehicle speed (speed limit), $g$ is the gravitational constant, $f$ is the coefficient of braking friction, $G$ is the grade in ft/ft, and $t_p$ is the perception/reaction time.

Once the SSD is calculated, the minimum curve length can be calculated. For a crest curve shown in figure 4, the minimum length can be found with the following equation: (AASHTO 268)

$$L_m = \frac{A \text{ SSD}^2}{1329}$$

Equation 2.1.2

![Figure 4. Stopping sight distance considerations for crest vertical curves.](image)

For a sag curve shown in figure 5, the minimum length can be found with the following equation: (AASHTO 273)

$$L_m = \frac{A \text{ SSD}^2}{400 + 3.5 \text{ SSD}}$$

Equation 2.1.3

![Figure 5. Stopping sight distance considerations for sag vertical curves.](image)
Where PVI is the point of intersection, PVC is a point on the vertical curve, PVT is the point of vertical tangent, H1 is the height of the driver’s eye, H is the height of the car’s headlight, H2 is the height of a roadway object, L is the length of the curve, and S is the sight distance.

**Example:** Shown in figure 6 is the vertical curve for the redesigned entrance. Note the dip in the existing ground level line illustrating the entrance construction over an existing ditch.

![Figure 6. Vertical curve example](image)

Calculating the SSD for the highway is a crucial computation to ensure that the oncoming traffic has plenty of time to react to a person pulling out from the entrance onto the highway. Also, a vehicle pulling out into the highway needs an ample sight distance to ensure there is not an oncoming vehicle. Microstation proves a valuable tool in finding the sight distance. Shown in figure 7, the sight distance can be found by simply drafting the line of sight from the vehicle in question (3.5ft above ground level) that is located at the station of the intersection across the crest of the vertical curve of the highway until the horizontal line is above the minimum object height level (2ft above ground level). The measured sight distances are both over 640ft. This is a safe sight distance to provide an adequate stop at the posted speed limit of 50mph. The calculated minimum SSD from the equation is about 460ft.
2.2) Horizontal Curve Fundamentals

The critical design feature of horizontal alignment is the horizontal curve that transitions the roadway between two tangent sections (figure 8). Thus, the key concern in this directional transition is the ability of a vehicle/driver to negotiate a horizontal curve safely and comfortably. The minimum radius that a vehicle can safely negotiate a horizontal curve at a given velocity can be found with the following equation: (AASHTO 146)

\[ R_v = \frac{V^2}{g(f_s + e)} \]

Where \( R_v \) is the minimum radius of the centerline of the innermost lane on the horizontal curve, \( V \) is the initial velocity of the automobile, \( g \) is the gravitational constant, \( f_s \) is the coefficient of side friction, and \( e \) is Superelevation. Superelevation is the slope
or banking of the roadway and is normal crowning is about 2%. Superelevation is necessary for adequate roadway drainage to prevent pooling and hydroplaning. Superelevation also provides sufficient side friction to keep vehicles securely on the road.

It is important to note that horizontal curve stationing, curve length, and curve radius (R) are typically measured with respect to the centerline of the road. In contrast, the radius determined on the basis of vehicle forces ($R_v$) is measured from the center of the innermost vehicle lane.

Also, it is important to note that the above minimum radius calculations assumes no sight obstructions along the curve. If a sight obstruction does exist additional calculations must be made to ensure the curve satisfies proper SSD requirements.

**Example:** Shown in figure 9 is the plan view of the horizontal curve for the redesigned entrance.

![Diagram](image.png)
The calculated maximum velocity for the given radius and super elevation of the curve using equation 2.2.1 is approximately 21mph. This is appropriate because it is approaching an intersection, large trucks can safely navigate the corner, and it efficiently ties the curve into the existing road. Figure 10 shows the results of running the Autoturn program, which is a resourceful and proficient tool that automates a vehicle’s path capabilities.

![Figure 10: Autoturn tool](image)

### 2.3) Cross Section Fundamentals

The cross sectional view is shown perpendicular from the centerline. (See figure 11) Cross sections are usually drafted every 25 feet. Cross sections illustrate the proposed template cuts and fills of the construction in the existing terrain, soil and pavement types and thicknesses, slope details, and dimensioning. Microstation makes drawing cross sections very simple and efficient. Once the vertical and horizontal curves and proposed templates have been drawn, Geopak an analysis program used in conjunction with Microstation, automatically generates the cross sections and calculates the soil volumes required for the project. This capability saves the engineer a great deal
of time, for these calculations by hand are tedious and the results are not nearly as accurate.

Figure 11. Cross section action
3.) Conclusion

While I have taken a road design course as a junior in civil engineering, this internship experience has proven invaluable in my understanding of transportation engineering. In college, the geometric and computational fundamentals of engineering are well covered; however, little is covered about the processes and procedures of an actual project. Furthermore, Universities are slow in updating their curriculum to the modern technological advances of the profession. Thus, using Microstation and Geopak, while working at the Department of Transportation has been very beneficial training.
4.) **Works Cited**


Road Design Manual. Iowa Department of Transportation 2004

Pottawattamie County Grade and Pave US 275 From Missouri River East to the I-29 Interchange Project Number: STP-275-3(29)—2C-78. Iowa Department of Transportation Highway Division 5/25/05