1.6 Design of highway alignment

As explained previously, the design of highways necessitates the determination of specific design elements, which include the number of lanes, lane width, median type (if any) and width, length of acceleration and deceleration lanes for on- and off-ramps, need for truck climbing lanes and for steep grades, curve radii required for vehicle turning, and the alignment required to provide adequate stopping and passing sight distances. One of the most important element of those determinations is a design of alignment, which is mostly governed by the design speed of vehicle.

The alignment that follows the natural topography is the most economical one. However, it is not necessary to adopt the lowest cost alignment option since the designer always must adhere to design standards which might not exist on the natural topography. When they are designed, both vertical and horizontal alignments has to complete each other in order to ensure a consistent and safer roadway. In addition, horizontal and vertical alignments have to be well coordinated to avoid sudden changes and visibility problems.

The alignment of a highway is a three-dimensional problem measured in x, y and z coordinates as illustrated based on a driver's perspective and shown in Figure 1.15. However, in highway design practice, three-dimensional design computations are cumbersome, and, what is perhaps more important, the actual implementation and construction of design based on three-dimensional coordinates has historically been prohibitively difficult. As a consequence, the three-dimensional highway problem is reduced to two-dimensional alignment problems as illustrated in Figure 1.16.

One of the alignment problems in Figure 1.6 corresponds roughly to *x* and *z* coordinates and is referred to as horizontal alignment while y coordinates (elevation) and is refereed to vertical alignment

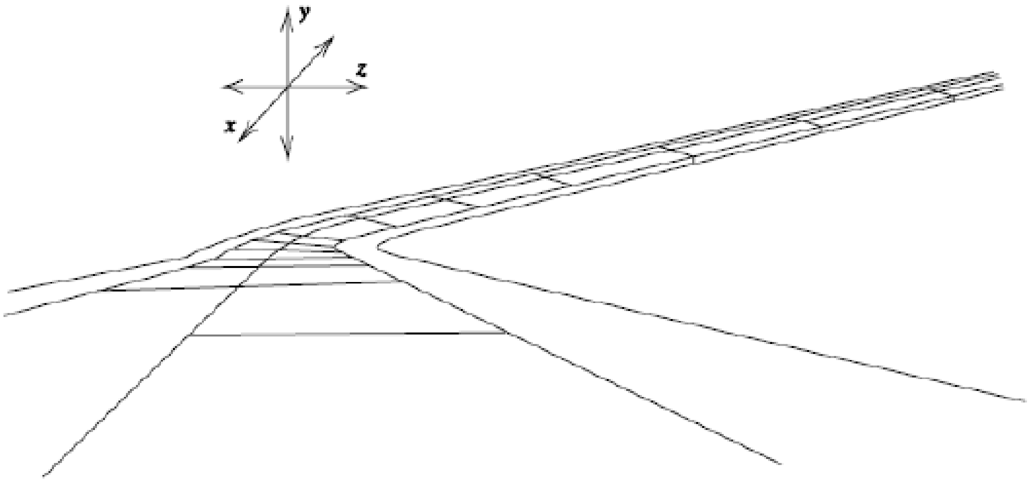

Figure 1.15: Highway alignment in three dimensions

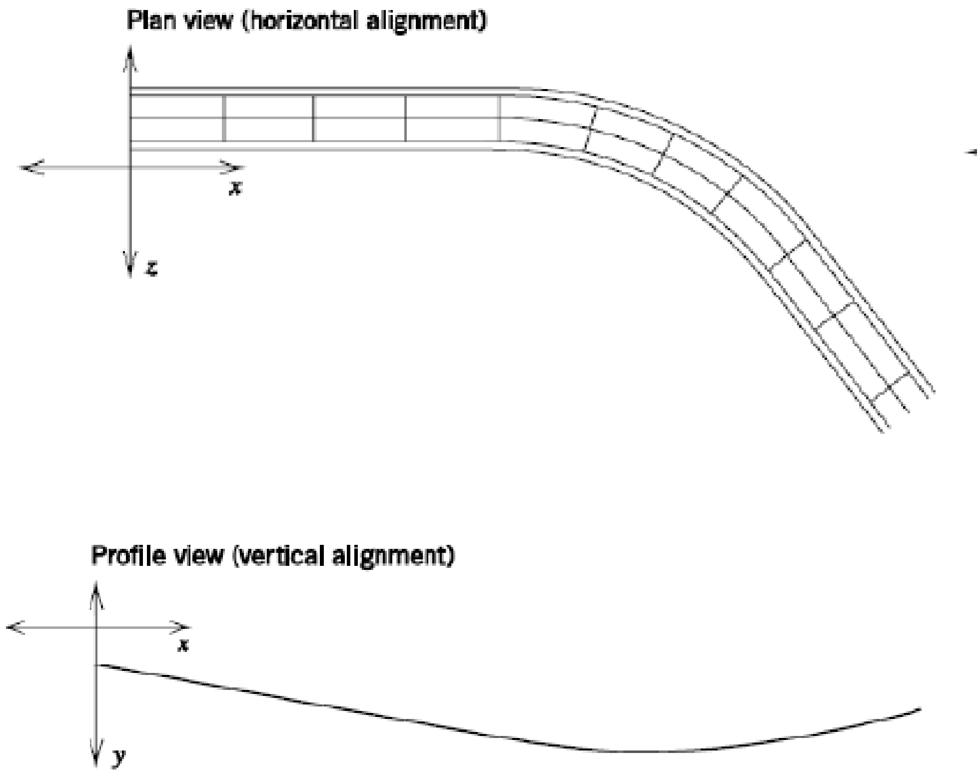

Figure 1.16: Highway alignment in two-dimensional views

1.6.1 Horizontal alignment

The critical aspect of horizontal alignment is the horizontal curve with focus on design of the directional transition of the roadway in a horizontal plane. In other words, a horizontal curve provides a transition between two straight (or tangent) sections of roadway as shown in Figure 1.17. These curves, which are circles segments, ensure smooth flow of traffic and "typically" same and consistent design speed of that provided on tangents. Therefore, a key concern in this directional transition is the ability of the vehicle to negotiate a horizontal curve However; in some design cases, it is difficult to ensure same design speed of tangents especially in urban area. This may consequently require a sharp radius. Furthermore, the design of highway is an interactive process where sometimes it is necessary to adjust the horizontal alignment based on the vertical alignment situation. Typical design of horizontal curve includes the determination of the minimum radius for a certain design speed and the other curve parameters those facilitating curve setting out.

a: Two-dimensional horizontal curve

b: three-dimensional horizontal curve

Figure 1.17: Horizontal curve

1.6.1.1 Tangents

Tangents is the straight parts of horizontal alignments, which could be expressed in terms of either bearings or azimuths. Azimuths represent angles turned clockwise from due north. On the other hand, bearings are expressed as angles turned either clockwise or counter clockwise from either north or south. For instance, the azimuth 290 is equivalent to the bearing north 70 west (or N70W) as presented in Figure 1.18. Generally, there are no limitations on the length of the tangents. In a flat terrain, the length of the tangents could be between 30 and 50 Km. It should be however noted that short curves at the end of long tangent must be avoided for safety consideration. Why?

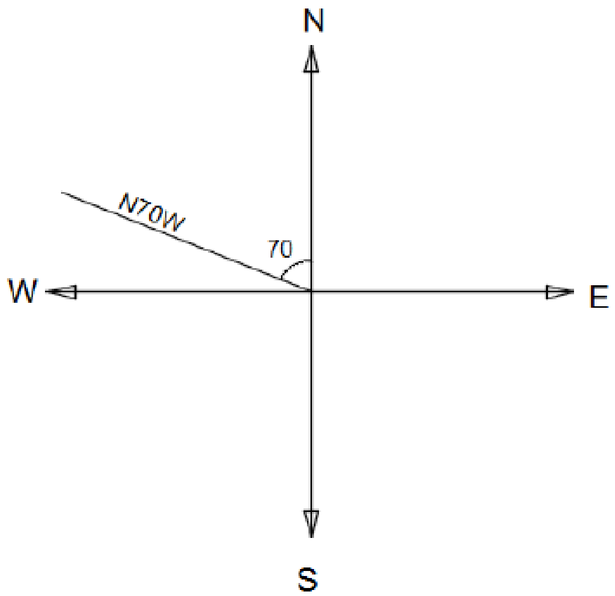

Figure 1.18: Horizontal tangent

1.6.1.2 Horizontal Curve

In connecting tangent (straight) sections of roadway with a horizontal curve, several options are available; simple circular curve, compound curves, reverse curves, and spiral curves. In general, from safety and comfort considerations, and to avoid shorter curve that create a kink impression, the minimum curve length should be (as a function of design speed in Kilometres):

L_{min}= 3V for major roads…………………………………………....8

L_{min}= 6V for freeway roads……………………………………………9

In terms of maximum curve length, it should not exceed approximately 1 Km (1000 meters), with the preferred maximum length being 800 meters. On curves with very large radii, that is, greater than 3000 meters, the limitation on maximum curve length is no longer applicable.

Simple Curve: it is the most obvious type compared to others as shown in Figure 1.19. It is just a curve with a single, constant radius. It is widely used to maintain the design speed and provide the driver a safe and smooth transition from a tangent to other.

Reverse Curves: they generally consist of two consecutive curves that turn in opposite directions. Those curves are used to laterally shift the alignment of a highway. The type of these curves is generally circular with equal radii.

It should be however noted that reverse curves are not recommended because drivers may find it difficult to stay within their lane as result of sudden changes to the alignment. Figure 1.20 shows an example of reverse curves.

Compound Curves: they consist of two or more curves, usually circular, in succession. Those curves are used to fit horizontal curves to very specific alignment needs, such as interchange ramps, interaction curves, or difficult topography. Care should be taken in design process of such curves, as this will make it difficult for drivers to maintain their lane position as they transition from one curve to the next. Figure 1.21 presents an example of compound curves.

Spiral Curves: these curves are used with a continuously changing radius. In general, they are sometime used to transition a tangent section of roadway to a circular curve. In such a case, the radius of the spiral curve is equal to infinity where it connects to the tangent section and ends with the radius value of the connecting circular curve at the other end. Spiral curves are not often used but they are sometimes used on high-speed roadways with sharp horizontal curves and are sometimes also used to gradually introduce the superelevation of an upcoming horizontal curve. Figure 1.22 show an example of spiral curve.

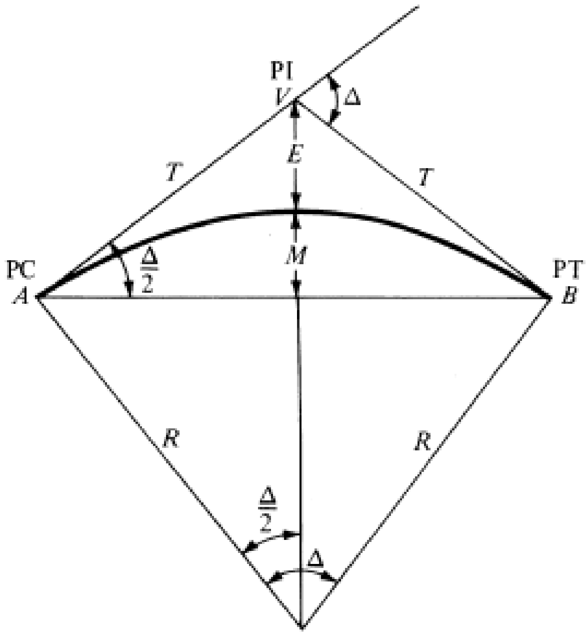

Figure 1.19: Horizontal curve

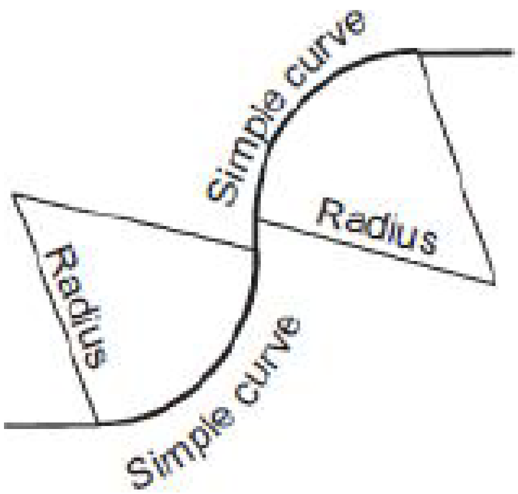

Figure 1.20: Reverse curve

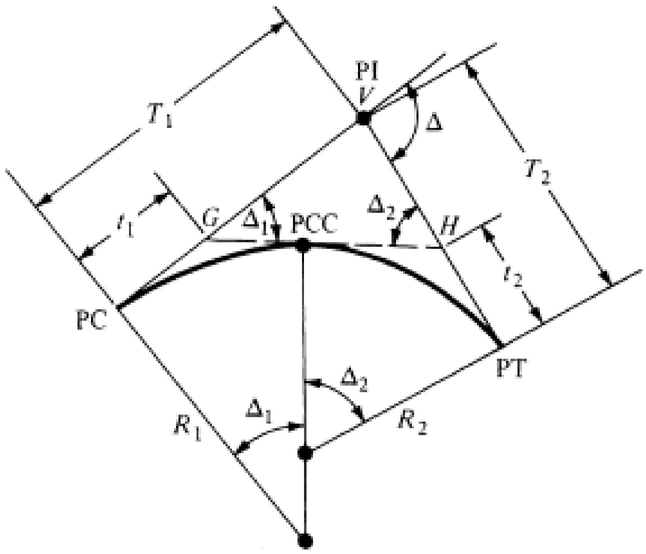

Figure 1.21: Compound curve

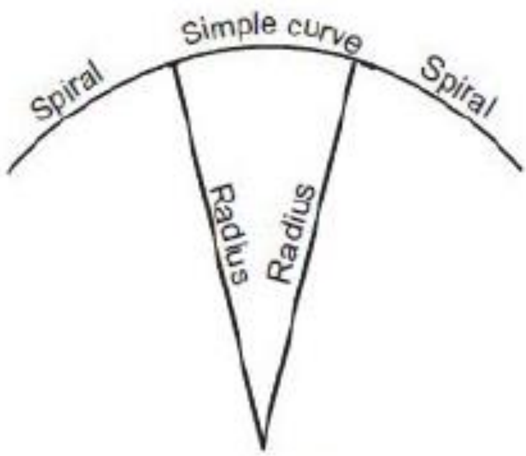

Figure 1.22: Spiral curve

1.6.2 Simple circular curve

Having mentioned that the simple circular curve is mostly and widely used in the design of highway alignment. The parameter of this kind of curves are previously presented in Figure 1.19. Those parameters can be calculated as follows:

$$D = \frac{3600}{2\pi R} = \frac{5729.58}{R}$$ 10

$$L = \frac{2\pi R\Delta}{360^\circ} = R\Delta_{rad}$$ 11

$$T = R \tan\frac{\Delta}{2}$$ 12

$$M = R\text{-}R \cos\left(\frac{\Delta}{2}\right)$$ 13

$$E = \frac{R}{\cos\left(\frac{\Delta}{2}\right)} - R$$ 14

$$C = 2R \sin\frac{\Delta}{2}$$ 15

TC station = PI station – T 16

CT station = TC station + L 17

R= radius of curve, **L**= length of curve, **T**= tangent length/distance, **M**= middle ordinate, **Delta**= central angle (deflection angle), **D**= degree of curvature, **C**=chord length, **PI**=point of intersection, **TC**= tangent to curve point (or PC, point of curvature), and **CT** =curve to tangent point (or PT, point of tangency)