Chapter 18

Vertical alignment - 2

18.1 Overview

As discussed earlier, changes in topography necessitate the introduction of vertical curves. The second curve of this type is the valley curve. This section deals with the types of valley curve and their geometrical design.

18.2 Valley curve

Valley curve or sag curves are vertical curves with convexity downwards. They are formed when two gradients meet as illustrated in figure 18:1 in any of the following four ways:

1. when a descending gradient meets another descending gradient [figure 18:1a].
2. when a descending gradient meets a flat gradient [figure 18:1b].
3. when a descending gradient meets an ascending gradient [figure 18:1c].
4. when an ascending gradient meets another ascending gradient [figure 18:1d].

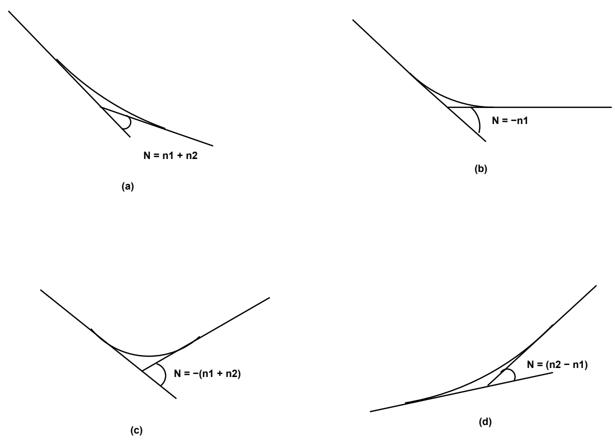

Figure 18:1: Types of valley curve

18.2.1 Design considerations

There is no restriction to sight distance at valley curves during day time. But visibility is reduced during night. In the absence or inadequacy of street light, the only source for visibility is with the help of headlights. Hence valley curves are designed taking into account of headlight distance. In valley curves, the centrifugal force will be acting downwards along with the weight of the vehicle, and hence impact to the vehicle will be more. This will result in jerking of the vehicle and cause discomfort to the passengers. Thus the most important design factors considered in valley curves are: (1) impact-free movement of vehicles at design speed and (2) availability of stopping sight distance under headlight of vehicles for night driving.

For gradually introducing and increasing the centrifugal force acting downwards, the best shape that could be given for a valley curve is a transition curve. Cubic parabola is generally preferred in vertical valley curves. During night, under headlight driving condition, sight distance reduces and availability of stopping sight distance under head light is very important. The head light sight distance should be at least equal to the stopping sight distance. There is no problem of overtaking sight distance at night since the other vehicles with headlights could be seen from a considerable distance.

18.2.2 Length of the valley curve

The valley curve is made fully transitional by providing two similar transition curves of equal length The transitional curve is set out by a cubic parabola $y = bx^3$ where $b = \frac{2N}{3L^2}$ The length of the valley transition curve is designed based on two criteria:

1. comfort criteria; that is allowable rate of change of centrifugal acceleration is limited to a comfortable level of about $0.6 m/sec^3$.

2. safety criteria; that is the driver should have adequate headlight sight distance at any part of the country.

Comfort criteria

The length of the valley curve based on the rate of change of centrifugal acceleration that will ensure comfort:

Let c is the rate of change of acceleration, R the minimum radius of the curve, v is the design speed and t is the time, then c is given as:

$$
\begin{aligned}
c &= \frac{\frac{v^2}{R} - 0}{t} \\
&= \frac{\frac{v^2}{R} - 0}{\frac{L_s}{v}} \\
&= \frac{v^3}{L_s R} \\
L_s &= \frac{v^3}{cR}
\end{aligned} \tag{18.1}
$$

For a cubic parabola, the value of R for length L_s is given by:

$$
R = \frac{L_s}{N} \tag{18.2}
$$

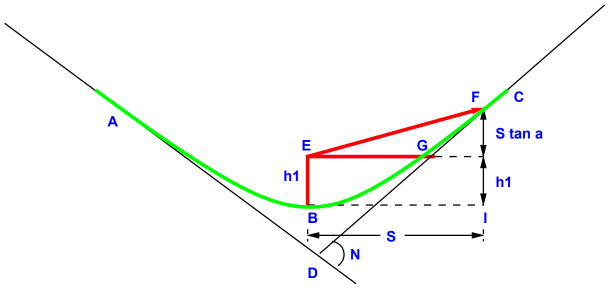

Figure 18:2: Valley curve, case1, $L > S$

Therefore,

$$\begin{aligned} L_s &= \frac{v^3}{\frac{cL_s}{N}} \\ L_s &= \sqrt[2]{\frac{Nv^3}{c}} \\ L &= 2\sqrt[2]{\frac{Nv^3}{c}} \end{aligned} \tag{18.3}$$

where L is the total length of valley curve, N is the deviation angle in radians or tangent of the deviation angle or the algebraic difference in grades, and c is the allowable rate of change of centrifugal acceleration which may be taken as $0.6 m/sec^3$.

Safety criteria

Length of the valley curve for headlight distance may be determined for two conditions: (1) length of the valley curve greater than stopping sight distance and (2) length of the valley curve less than the stopping sight distance.

Case 1 Length of valley curve greater than stopping sight distance ($L > S$)

The total length of valley curve L is greater than the stopping sight distance SSD. The sight distance available will be minimum when the vehicle is in the lowest point in the valley. This is because the beginning of the curve will have infinite radius and the bottom of the curve will have minimum radius which is a property of the transition curve. The case is shown in figure 18:2

From the geometry of the figure, we have:

$$\begin{aligned} h_1 + S\tan\alpha &= aS^2 \\ &= \frac{NS^2}{2L} \\ L &= \frac{NS^2}{2h_1 + 2S\tan\alpha} \end{aligned} \tag{18.4}$$

where N is the deviation angle in radians, h_1 is the height of headlight beam, α is the head beam inclination in degrees and S is the sight distance. The inclination α is ≈ 1 degree.

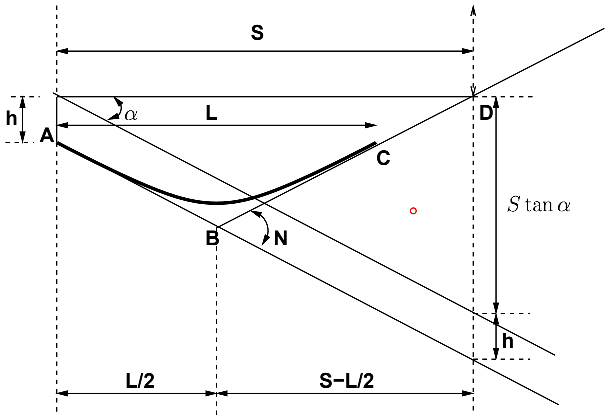

Figure 18:3: Valley curve, case 2, $S > L$

Case 2 Length of valley curve less than stopping sight distance ($L < S$)

The length of the curve L is less than SSD. In this case the minimum sight distance is from the beginning of the curve. The important points are the beginning of the curve and the bottom most part of the curve. If the vehicle is at the bottom of the curve, then its headlight beam will reach far beyond the endpoint of the curve whereas, if the vehicle is at the beginning of the curve, then the headlight beam will hit just outside the curve. Therefore, the length of the curve is derived by assuming the vehicle at the beginning of the curve . The case is shown in figure 18:3.

From the figure,

$$h_1 + s\tan\alpha = \left(S - \frac{L}{2}\right) N$$

$$L = 2S - \frac{2h_1 + 2S\tan\alpha}{N} \tag{18.5}$$

Note that the above expression is approximate and is satisfactory because in practice, the gradients are very small and is acceptable for all practical purposes. We will not be able to know prior to which case to be adopted. Therefore both has to be calculated and the one which satisfies the condition is adopted.

18.3 Summary

The valley curve should be designed such that there is enough headlight sight distance. Improperly designed valley curves results in extreme riding discomfort as well as accident risks especially at nights. The length of valley curve for various cases were also explained in the section. The concept of valley curve is used in underpasses.

18.4 Problems

1. A valley curve is formed by descending gradient n_1= 1 in 25 and ascending gradient n_2= 1 in 30. Design the length of the valley curve for V=80kmph. (Hint: c=0.6 m/cm^3, SSD=127.3m) [Ans: L=max(73.1,199.5)]