Geometric Design of Highway Using HTML Programming

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Abstract— **The exponential growth in highway traffic in terms of number of vehicles as well as increased in the magnitude and frequency of loading of commercial vehicles had modelled challenging complications to the highway engineering professionals dealing with planning, design, construction, maintenance and management of the highway network. Due to consistent research and development efforts in various developed and developing countries, there had been various advances in the area of highway engineering and technology.**

The geometric design of highway in the elementary sense was a tedious job if the manual calculations were brought in practice with the available equations, derivations and the related formulae. But, the availability of the computer-based program with a user-friendly nature for executing the elementary geometric design became a solution to overcome the challenge of the highway design.

The study carried out in this paper was based on the geometric design of highway using computer based programming. The geometric design that had been taken into account comprised of the basic elements of highway geometric design, safe sight distance, overtaking sight distance, horizontal curve, transition curve and vertical curve along with their detailed components involved in the highway design. The purpose of this paper was to develop computer-based conceptual geometric design model for highway projects using HTML web application of computer programming. The approach was to assemble fundamental of geometric design conception of highway mentioned above using standard derivations and related equations of highway engineering.

Keywords—**Highway, Highway Geometric design, HTML Web programming of Highway, Transportation.**

I. INTRODUCTION

The main principle of satisfactory transportation system was to provide safe, cost-effective and efficient transportation facility for the travel of commuters and transportation of goods. Transportation by highway system was the only mode which could give maximum flexibility of service from origin to destination, to one and all. The discipline of transportation dealing with the planning, design, construction and maintenance of highway facilities was defined as Road or Highway Engineering.

The characteristics of transportation system were listed here [1]:

1) Highways were used by various types of road vehicles (cars, buses, trucks etc.) pedal cycles, animal drawn vehicles and also the pedestrians.
2) Highway transport set-up required the lowest initial speculation in comparison to that for the infrastructure of other transportation means.
3) Highways offer complete freedom to traveller to use of the highway facilities at any time opportune to them or to move the vehicle from a lane of the highway to the adjoining one and from one highway to another, according to the requirement and expediency.
4) It is possible to travel directly from the respective places of source to the terminus by highway vehicles.

A. *Importance of Geometric Design*: The geometric design of highways dealt with following elements:

1) Cross section element
2) Sight distance considerations
3) Horizontal alignment details
4) Vertical alignment details
5) Intersection details and curves

B. *Design controls and criteria*: The important factors which control the geometric elements were:

1) Design speed
2) Topography or terrain
3) Traffic factors
4) Design hourly volume and capacity
5) Environmental and other factors

C. *Highway Cross Section Elements*:

1) *Cross Slope or Camber*: It was the slope provided to the highway surface in the transverse direction to drain off the rain water from the highway surface. Drainage and quick disposal of water from the pavement surface by providing cross slope is considered important. In the field, camber of the pavement cross section was provided with a suitable shape. Different shapes that were commonly adopted were parabolic, straight line or straights with parabolic curve at the top as shown in Fig.1. In cement-concrete pavements, straight line camber was usually adopted as it was easy to lay the same during construction and also as the camber required was relatively flat.

2) *Gradient*: Gradient was the rate of rise or fall along the length of the highway with respect to the horizontal. It was expressed as a ratio of 1 in x (1 vertical unit to x horizontal units), The gradient was also expressed as a percentage, such as n %, the slope being n vertical units to 100 horizontal units.
3) *Sight Distance*: Sight distance was the length of highway visible ahead to the driver at any instance. Sight distance available at any location of the carriageway was the actual distance a driver with his eye level at a specified height above the pavement surface has visibility of any stationary or moving object of specified height which is on the carriageway ahead. The sight distance between the driver and the object is measurement along the highway surface.
   Types of sight distance: Sight distance required by drivers applies to both geometric designs of highways and for traffic control [2]. Three types of sight distance situations were considered in the design:
   - Stopping sight distance (SSD) or absolute minimum sight distance
   - Safe overtaking sight distance (OSD) or passing sight distance
   - Safe sight distance for entering into uncontrolled intersections

   Apart from the three situations mentioned above, the following sight distances were considered by the IRC in highway design:
   1) Intermediate sight distance
   2) Head light sight distance
4) *Overtaking Sight Distance*: If all the vehicles travel along a highway at the design speed, then theoretically there should be no need for any overtaking. In fact, all vehicles did not move at the design speed as each vehicle driver was free to travel at lower speeds and this was particularly true under 'mixed traffic' conditions. In such circumstances, it was necessary for fast moving vehicles to overtake or pass the slow-moving vehicles. Therefore, efforts should be made to provide adequate sight distance along the highway alignment to enable vehicles travelling at design speed to safely overtake slow moving vehicles.
   The minimum distance opened to the vision of the driver of a vehicle intended to overtake slow vehicle ahead with safely against the traffic of opposite direction was known as the 'minimum overtaking sight distance' (OSD) or the 'safe passing sight distance' available.
5) *Grade Compensation*: When sharp horizontal curve was to be introduced on a highway which had been already the maximum permission gradient, then the gradient should be decreased to compensate for the loss of tractive effort due to the curve. This reduction in gradient at the horizontal curve was called grade compensation.
   According to the IRC the grade compensation was not necessary for gradients flatter than 4.0 percent and therefore when applying grade compensation correction, the gradients needed not be eased beyond 4.0 percent. The compensated gradient was = (ruling gradient minus grade compensation)
6) *Superelevation*: In order to counteract the effect of centrifugal force and to reduce the tendency of the vehicle to overturn or skid, the outer edge of pavement was raised with respect to the inner edge, thus providing a transverse inclination to the pavement surface was known as horizontal curve. This transverse inclination to the pavement surface was known as 'superelevation' or banking.
   Thus, the superelevation '*e*' required on the horizontal curve depends on three factors, friction or the transverse skid resistance f. Therefore, in order to assess the required superelevation e, the speed was taken as equal to the design speed of the highway and the minimum value of transverse skid resistance, f for design purpose is taken as 0.15.
7) *Extra widening*: On horizontal curves, especially when they were not of very large radii, it was common practice to widen the pavement slightly more than the normal width. The object of providing extra widening of pavements on horizontal curves.
   The required extra widening of the pavement at the horizontal curves, W_e depends on (i) the length f wheel based of the vehicle l, radius of the curve negotiated R and (ii) the psychological factor which is a function of the speed of the vehicle and the radius of the curve.

8) *Setback Distance*: In the design of horizontal alignment, the sight distance along the inner side of the curves should be considered. Where there were sights obstruction like buildings, cut slopes, or tree on the inner side of the curves, either the obstruction should be removed or the alignments should be changed in order to provide adequate sight distance. It might be sometime possible to make some adjustments in the normal highway cross section to make up small deficiencies in sight distance.
   The *clearance distance* or *set back distance* required from the center line of a horizontal curve to an obstruction on the inner side of the curve to provide adequate sight distance depended on the following factors:
   1) Required sight distance, S
   2) Radius of horizontal curve, R
   3) Length of the curve, L_c
9) *Curve Resistance*: The automobiles were steered by turning the front wheels, but the rear wheels did not turned. When a vehicle driven by rear wheels moves on a horizontal curve, the direction of rotation of rear and front wheels were different and so there was some loss in tractive force. The loss of tractive force due to turning of a vehicle on a horizontal curve, which was termed as 'curve resistance' [2].
10) *Horizontal Transition Curve*: A transition curve had a radius which decreases from infinity at the tangent point a designed radius of the circular curve. When a transition curve was introduced between a straight and circular curve, the radius of the transition curve decreases becomes minimum at the beginning of the circular curve. The rate of change of radius of the transition curve will depend on the equation of the curve or its shape.

A transition curve which was introduced between the straight and a circular curve would help also in gradually introducing the designed super elevation and the extra widening necessary. Thus, the functions of transition curve in the horizontal alignment of highway might been summed up into the following points:

1) To introduce gradually the centrifugal force between the tangent point and the beginning of the circular curve, avoiding a sudden jerk on the vehicle.
2) To enable the driver, turn the steering gradually for his own comfort and security
3) To enable gradual introduction of the designed superelevation and extra widening of pavement of the start of the circular curve
4) To improve the aesthetic appearance of the highway

The ideal shape of a transition curve should be such that the rate of introduction of centrifugal force or the rate of change of centrifugal acceleration should be consistent.

11) *Vertical curve*: Due to change in grade in the vertical alignment of highway, it was necessary to introduce the vertical curve at the intersections of different grades to smoothen out the vertical profile and thus ease off the changes in gradients for the fast-moving vehicles.
The vertical curves used in highway might been classified into two categories:
   1) Summit curves or crest curves with convexity upwards
   2) Valley curves or sag curves with concavity upward

When a fast-moving vehicle travels along a summit curve, the centrifugal force would been acted upward, against gravity and hence a part of the self weight of the vehicle was relieved resulting in reduction in pressure on the tyres and on the suspension springs of the vehicle suspensions.

- Summit Curve: The design of summit curve was only governed by considerations of sight distance and therefore transition curves were not necessary. Circular summit curve was ideal as the sight distance available throughout the length of circular curve was constant. From this view point, transition curve might been said to be even undesirable to be used on summit curves. This was because the radius of curvature and hence the sight distance would vary from point to point along the length of curve.
- Valley Curve: Valley curves or sag curves with convexity downwards were formed. As fast moving vehicles negotiate valley curves, the centrifugal force developed acted downward in addition to the self weight, thus additional pressure on the suspension system of the vehicle and discomfort to passengers due to impact, unless the valley curve was properly designed and laid.
  Therefore, the important factors to be considered in valley curve design were:
  a. Impact free movement of vehicles at design speed or the comfort to the passengers
  b. Providing adequate sight distance under head lights of vehicles for night driving
  c. Locating lowest point of the valley curve for providing suitable cross drainage facilities so as to prevent stagnation of water during rains.

II. Methodology

The working of the programming was based on the fundamental equations referred from standard reference books. Any equation defining the characteristics of the highway was dependent on several factors. The formulae were arranged as per their category of their relevance with the concerned chapters. This section provided the brief information about the various equations brought in practice while developing the program.

A. *Basic Elements of Highway Geometric Design*

This module consisted of determination of the camber, gradient and compensated gradient which was described as follows:

1) *Camber:* On the basis of the profile of the highway, the camber was classified as [2]:

- *Parabolic:* The profile was flat at the middle and steeper towards the edges as shown in Fig 1. The depth, *y* of the highway from the crown to the base of the highway for parabolic camber was given by the equation: $y = (2x^2/Wn)$, where, *x*: horizontal components from centre of highway; *n*: slope of the highway; *W*: width of the highway.

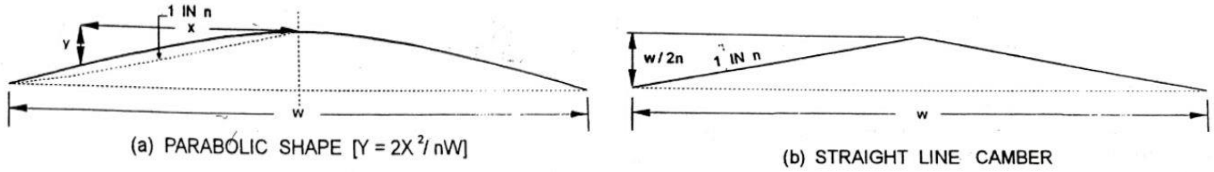


Fig. 1: Camber Shapes

- *Straight Line Camber:* Uniform cross slope on either side of centre of the highway was provided as shown in Fig 1. The depth, *y* of the highway from the crown to the base of the highway for straight line camber was given by the equation: $y = (W/2n)$,
  where, elements had their usual meaning.

2) *Gradient*

For better drainage and smooth flow of traffic, the camber (*C*) of the highway was approximately equal to the half of the longitudinal gradient i.e. $G = 2C$ [3].

3) *Grade Compensation*

The reduction given to the gradient when a gradient came along with horizontal curve was represented by the grade compensation *(GC)*. As per the recommendations of Indian Highway Congress *(IRC)*, grade compensation given to the gradients should not be less than 4% as: $GC = (30+R)/R$ *or* $(75/R)$ whichever was less. Where *R*: radius of the curve of highway.

The grade to be provided on the highway after the grade compensation constituted Compensated Gradient *(CG)* given as: $G - GC = CG$. As per the recommendations of Indian Highway Congress *(IRC)*, compensated grade should not be less than 4%.

B. Safe Sight Distance(SSD)

The formulation of the safe sight distance was based on lag distance and braking distance. The distance travelled by the vehicle during total reaction time was called lag distance (*L*), given as: $L = V.t$, where V is velocity in m/s and *t* is the reaction time in seconds. The view of Safe sight distance was as shown in Fig. 2.

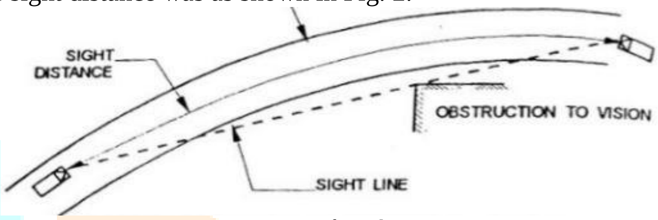


Fig. 2: Safe Sight Distance

The distance travelled after application of the brakes, to a dead stop position was called as breaking distance which was formulated as: S_b: $(V^2/(2g\mu)$, where *g*: acceleration due to gravity, m/s^2; μ: coefficient of longitudinal friction.

Intermediate Sight Distance *(ISD)* was twice the safe sight distance formulated as: $ISD = 2\ SSD$.

C. Overtaking Sight Distance (OSD)

The minimum distance opened to the vision of the driver of a vehicle intending to a vertex slow vehicle ahead with safety against the traffic of opposite direction was called minimum overtaking sight distance *(OSD)*. The OSD was formulated as per the type of the traffic on the highway mentioned below:

1) *One-way traffic:* $OSD=0.278V_Bt + [2(0.2V_B + L) + 0.278V_B(4S/a)^{0.5}]$, where, V_B: velocity of the vehicle to be overtaken in kmph; t: reaction time taken by the driver; L: length of the vehicle; S: distance between the test vehicle and the vehicle ahead of the test vehicle; a: acceleration in *m/s*. The Fig. 3 shows the meaning of notations.

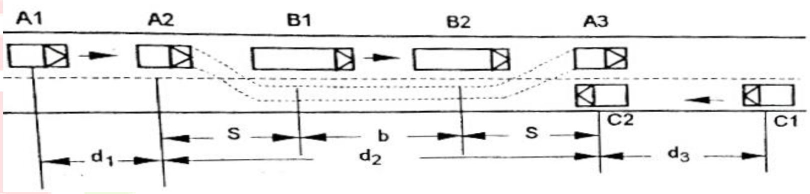


Fig. 3: Overtaking Sight Distance

2) *Two-way traffic:* $OSD=0.278V_Bt + [2(0.2V_B + L) + 0.278V_B(4S/a)^{0.5}] + [0.278V_c(4S/a)^{0.5}]$, where, V_B: velocity of the vehicle to be overtaken in kmph; t: reaction time taken by the driver; L: length of the vehicle; S: distance between the test vehicle and the vehicle ahead of the test vehicle; a: acceleration in *m/s* and V_c: velocity of the vehicle travelling against the test car in kmph.

D. Horizontal Curve

The curve was provided at the turning of the highway in order to had alignment of horizontal highways while changing the direction of vehicle in a specific direction. It was provided when there was an obstacle like geological structure or the limited availability of the land in the given region.

1) *Super-elevation:* It was the cross slope provided on the highway on a horizontal curve as shown in Fig.4. It was further elaborated as follows (as per the program development) [4]:
   - The general equation considered over the curve highway for friction and superelevation was given by: $e + \mu = [V^2/(127R)]$
   - The super-elevation required to balance the vehicle over a curve only with suer-elevation without considering friction was given by: $e = [V^2/(127R)]$.
   - Suer-elevation for mixed traffic or design super elevation was given as: $e = [V^2/(225R)]$.

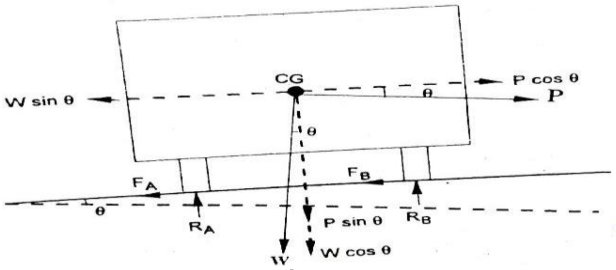


Fig. 4: Superelevation

2) Extra Widening of Horizontal Curve

The extra widening referred to the additional width of carriageway that was required on the curve section of highway over and above that required on a straight alignment as shown in Fig.5. Total widening *(W_e)* was the sum of mechanical widening *(W_m)* of the highway along with psychological widening *(W_{ps})* of the highway. The equation was given by: $W_e = W_m + W_{ps} = [(nL^2/(2R)] + [V/(9.5R^{0.5})]$, where, *n:* number of lanes; *L:* length of the wheel base of largest vehicle in metres.

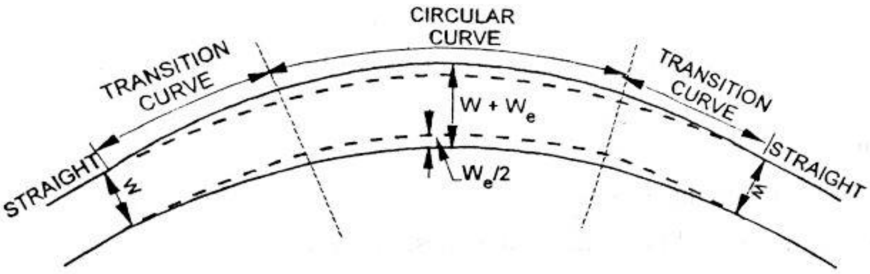


Fig. 5: Extra widening [1]

3) Set Back Distance (m)

Setback or the clearance was the distance required from the centre-line of horizontal curve to an obstruction on the inner side of the curve to provide an adequate sight distance on the horizontal curve as shown in Fig.6.

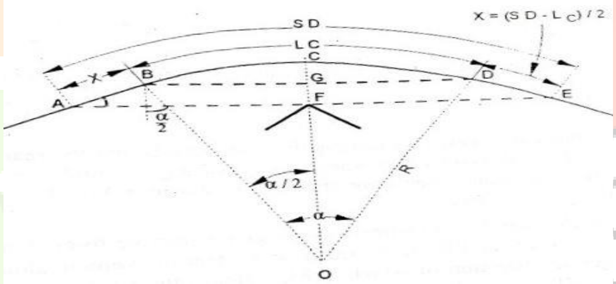


Fig. 6: Set Back Distance

There were two cases for approximate formulae of the setback distance *(m)*:

- When the length of the curve was more than the sight distance then the equation was given by: $m = [S^2/(8R)]$.
- When the length of the curve was less than the sight distance, then the equation was given by: $m = [L(2S-L)/(8R)]$.

4) Curve Resistance

The loss of tractive force due to turning of vehicle on a horizontal curve was given by: $CR = T(1-\cos\theta)$

E. Transition Curve

The curves were introduced between straight and circular curve to enable the driver turn the steering gradually for comfort and security such that super elevation, extra widening, and the introduction of centrifugal force all were gradually implemented in the highway. The different shapes of transition curves were as shown in Fig.7.

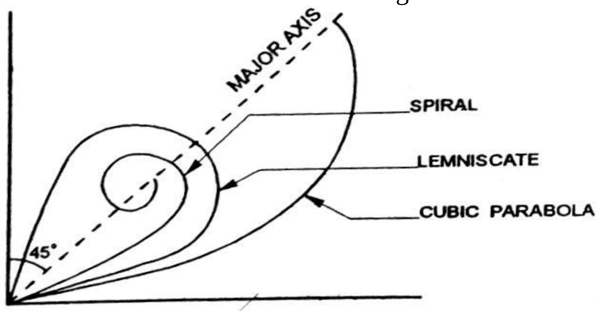


Fig. 7: Transition Curve Shapes

1) For plain terrain:

The length of the transition curve (L) was given by: $L = 0.02143V^3/(C\times R)$.
It can be obtained using empirical equation given by IRC as: $L = 2.7V^2/R$, where, V: velocity in kmph; R: radius of curve in metres; C: rate of change of centrifugal acceleration or jerk which can be obtained as: $C = 80/(75+V)$;

- For the rate of change of super elevation, if pavement was rotated with respect to outer edge, then the length of the transition curve so obtained was given by: $L_s = Ne\ (W+W_e)$, where, W: width of the pavement and N: rate of change of super elevation.
- If the pavement was rotated with respect to the centre-line, then: $L_s = [Ne\ (W+W_e]/2$.

2) *For hilly terrain:*

All the equations of determining the length of the transition curve remained the same except the equation provided by the IRC as: $L = V^2/R$.

F. Vertical Curve

The curves were provided in elevation at change of gradient such that when the curves were complex, the grades met at the summit and when concave, they met at sag [4]. On this basis, they were classified and designed as:

1) *Design of Summit Curves:*

- When the length of summit curve was greater than SSD, then the calculated length was: $L = (NS^2/4.4)$, where, N: deviation angle; S: stopping sight distance.
- When the length of summit curve was less than SSD, then the calculated length was: $L = 2S\text{-}(4.4/N)$.
- When the length of summit curve was greater than OSD/ISD, then the calculated length was: $L = (NS^2/9.6)$.
- When the length of summit curve was lesser than OSD/ISD, then the calculated length was: $L = 2S\text{-}(9.6/N)$.
  where, elements had their usual meaning as shown in Fig. 8.

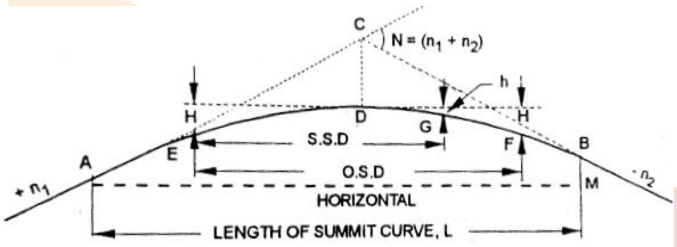


Fig. 8: Summit Curve

2) *Design of Valley Curves:*

- The length of the valley curve was given by: $L = 0.38\ (NV^3)^{0.5}$.
- When the length of valley curve was greater than SSD, then the calculated length was: $L = NS^2/\ (1.5+0.0355)$
- When the length of valley curve was lesser than SSD, then the calculated length was: $L = 2S - [(1.5+0.0355)/N]$.
- The ratio of the maximum centrifugal force to the weight of the vehicle defined as impact factor (I) can be expressed in percentage as: $I = 1.6NV^2/L$.
  Where, elements had their usual meaning as shown in Fig. 9.

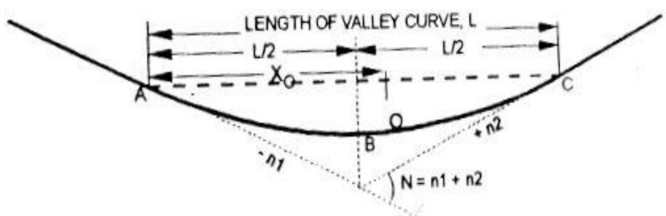


Fig. 9: Valley Curve

III. Software Development

In the previous section, there was the detailed explanation of the methodology adopted for the development of the program. In this section, the actual development and the related pathway network that was brought in practice for the execution of the computer based program.

The entire methodology explained in the previous section had been classified into basic 6 units. Fig. 10 shows the pathway network developed for each of the unit. The program for the execution of the first methodology adopted i.e. basic elements of geometric design which was mentioned in section II.

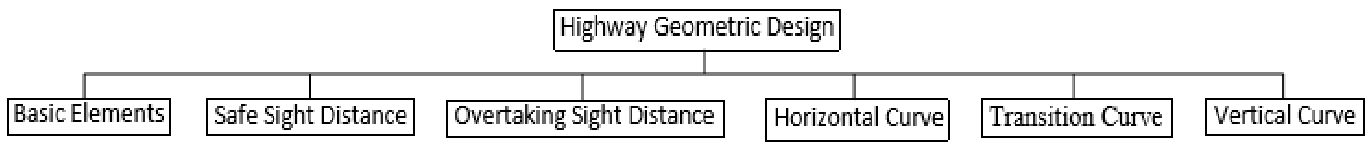


Fig.10: Units of Methodology in Highway Geometric Design

For the determination of the safe sight distance (SSD), the program asked to enter the values of reaction time, velocity of the vehicle slope of the highway, breaking efficiency and longitudinal friction factor. The result displayed on the execution of the program was SSD, and ISD. The pathway network was shown in Fig. 11. The standard symbols that were used in the flowchart was already explained in the section II.

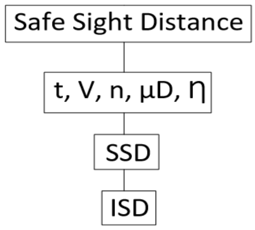


Fig 11: Flowchart for Safe Sight Distance

For the determination of the overtaking sight distance (OSD), the program asked to mention the type of the traffic, and the values of velocity of the vehicle, reaction time, length of the test vehicle and acceleration of the overtaking car should enter. The result displayed on the execution of the program was the OSD and the length of the overtaking zone. The pathway network was shown in Fig. 12. The standard symbols were used in flowchart was already explained in the section II.

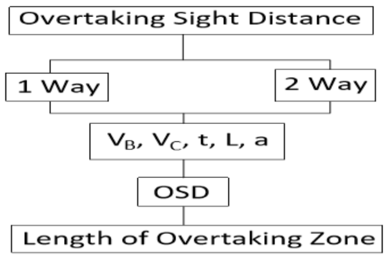


Fig 12: Flowchart for Overtaking Sight Distance

For the determination of the horizontal curve of the highway to be designed, the program asked to enter one of the characteristics among the four provided as shown in Fig. 13. The value of the respective choice was entered from the given menu and the result was displayed on the execution of the program. The result was super elevation (general, equilibrium, and design)/ extra widening to be provided/ set back distance / curve resistance depends on choice. The pathway network was shown in Fig. 13. The standard symbols were used in flowchart was already explained in the section II.

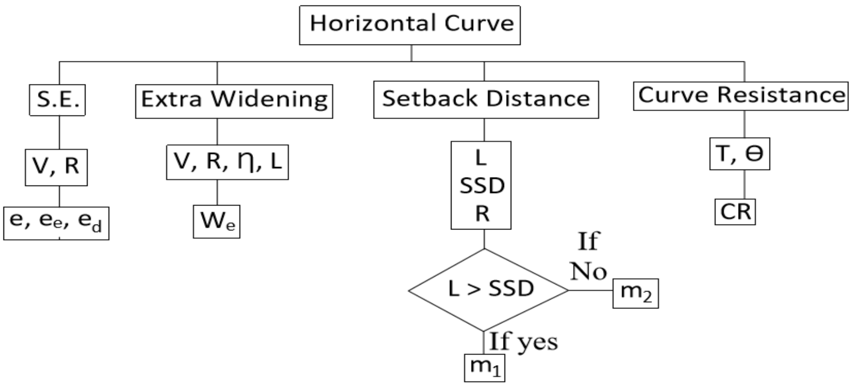


Fig 13: Flowchart for Horizontal Curve of the Highway

For the determination of the transition curve of the highway to be designed, the program asked to enter the type of terrain. The type of terrain was selected and respective values were entered. The result displayed on the execution of the program was the length of transition curve and shift required for circular curve to meet the transition curve. The pathway network was shown in Fig. 14. The standard symbols were used in flowchart was already explained in the section II.

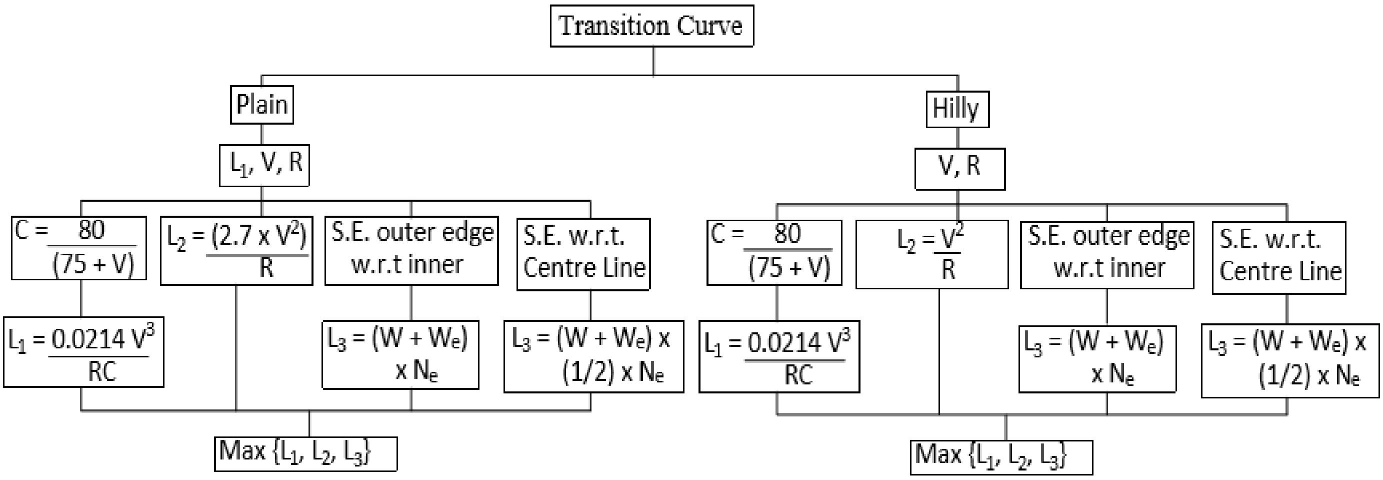


Fig 14: Flowchart for Transition Curve of the Highway

For the determination of the vertical curve of the highway to be designed, the program asked to enter the type of particular design i.e. design of summit curve or the valley curve. The value of the respective design was entered and the result was displayed on the execution of the program. The result was length of the summit curve / the length of the valley curve (according to the comfort condition and head light sight distance) and the impact factor depends on choice. The pathway network was shown in Fig.15. The standard symbols were used in flowchart was already explained in the section II.

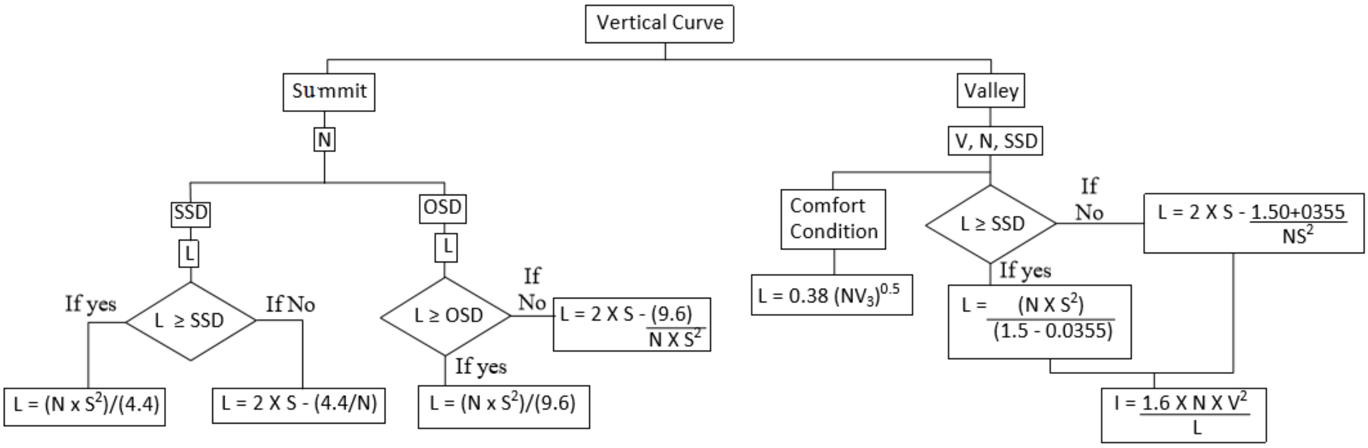


Fig 15: Flowchart for Vertical Curve of the Highway

IV. RESULT ANALYSIS

In this section, a problem was solved by using equations mentioned in section II manually and obtained result was analysed with the software model discussed in order to validate the program for solving the problems of Transportation Engineering.

Problem Statement:

Design a 2- lane 2-way National Highway for Rolling terrain having the horizontal curve of 150m and the cross-section of the highway is designed as parabolic in shape.
Assume longitudinal friction as 0.35 and lateral friction as 0.15
Acceleration for overtaking on the Highway is to be taken as 1 m/s^2
Permissible gradient is 7%
Average length of wheel base= 6m
Super-elevation is achieved by rotating outer edge with respect to inner edge
Difference in gradients=0.1

Solution by Manual Calculation:

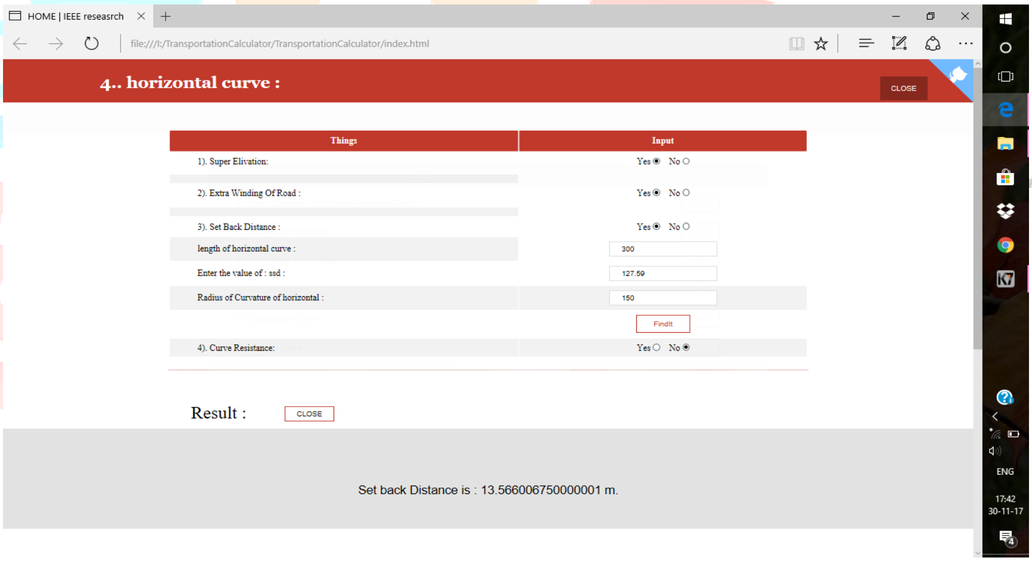
Using the Formulae mentioned in section II for the corresponding parameters, the output had been calculated and tabulated in the Table I below with due consideration of assumed value of certain parameters.
Assuming overtaking reaction time = 2 sec
Assuming Driver's Reaction time as per PIEV theory =2.5 sec

Jerk, C = [80/ (75 + 80)] = 0.516
Assuming the length of curve greater than S.S.D.

TABLE I
PARAMETERS FOR DESIGN OF NATIONAL HIGHWAY

Parameters	**Results**
A) Pavement Characteristics	
Equation of Cross-section of Camber	$y=3.809x^2$
B) Sight Distances	
1) Safe Sight Distances	127.59 m
2) Overtaking Sight Distance	227.44m
3) Intermediate Sight Distance	225.18m
C) Horizontal Curve	
1) Super- Elevation	7%
2) Extra Widening	0.9275 m
3) Set-Back Distance	13.702 m
4) Curve Resistance	
D) Transition curve	
1) Length of Transition	141.782 m
2) Shift	5.584 m
E) Vertical Curve	
1) Length of Summit Curve	369.98 m
2) Length of Valley Curve	272.88 m

Solution by Web Application: Accordingly, the data from the above problem was used as an input to the web application developed in this research. One of the screenshot of the result executed by the program is shown in Fig. 16:



By comparing the measured values obtained using manual calculation with the values so obtained from the web application, the study concluded that there were no variations in the result of these two approaches and the results so obtained by the execution of the program was found consistent with the manual calculation. Hence, the program developed in this paper was found consistent with the methodology so adopted with respect to the highway geometric design.

V. Conclusions

The software programming developed in this paper afforded a fundamental tactic of analytical cum mathematical approach using computer-based programming. The empirical relations and the different formulae of highway geometric design cast-off in this paper were already in existence in the standard reference books and Indian Highway Congress (IRC). This had been referred in study for developing the software of the process using HTML language of computer programming in order to minimize time consuming tedious manual calculations. The present paper tried to associate the fundamental notion of the concept of the *highway engineering of geometric design* with the computer-based programming. The interpretation regarding the highway design was based on this notion that it could be a tedious job if the manual calculation was brought in practice with the available equations, derivations and the related formulae. But, the availability of the computer-based program like the one which was explained in this paper with a user-friendly nature for executing the elementary program of highway design was definitely a solution to overcome the various challenges on the planning and design of the highway.

Hence, it can be concluded that the methodology of understanding the conceptions of highway design provided a preliminary approach to the undergraduates to link the practical design of the highway with computer programming to develop their interdisciplinary approach towards learning. The future scope of this paper was to transmute this HTML program into an android application for improved use of this contemporary program.

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