PERSPECTIVE OF CURVE COMBINATION

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Abstract: The main objective of this paper is to study the effects of the different radii in horizontal and vertical curves combinations with and without transition, and with and without superelevation in perspective pictures. Another purpose is to acquire an in-depth knowledge of the MOSS method of producing road perspective drawings. A systematic study was made on perspective of some road designs using combinations of horizontal and vertical geometric elements. Experiments were executed by producing sets of perspective drawings containing accurate perspective views. The discussion of the study results of the experiment are mentioned based on the effects of three radius curves, transition and superelevation. The presented outputs are curves to the left and curves to the right.

1. INTRODUCTION

Perspective drawings represent one of the major phases in highway design.. Until recent times, highway design is based principally on the viewpoint of driving dynamics. The view of the driver of the road ahead makes a contribution to the safety of the road and the comfort of the driver. Hence, perspective drawing is a necessary requirement in evaluating the guidance presented by the road alignment to the driver.

Road perspective drawings can be produced by means of manual drawing techniques and the use of computer programs. It is known that when the final design stages of a road have been reached the picture produced by the computer is most efficient. Thus, manually drawn pictures are time consumming, wasteful and useless exercise if computers are available. The basic principle of perspective drawing is the central projection. The location of points on the road is used for the computation of the image in the picture plane as they are projected from the center of vision. The requirement when setting up a perspective view of an object is to obtain accurate information. This information is usually in a form of plan, elevation and section. Usually, it is from the plan where the perspective view is projected and height is measured from the elevation and section.

In this study, the MOSS Program has been generated in the development of perspective views of the road. MOSS is a large computer program and a new tool used in the design of roads. This program allows the creation of perspective drawing of road and terrain model and even the combination of the two. It produces a plan of perspective views of a road from a desired observation point of a complete alignment showing the centerline, kerbline, catchline or interface, etc..

1.1 Essential Feature of Road Perspective

In a good road perspective design process, the length of vertical and horizontal curves must be nearly equal and if the curves are not equal in length the horizontal curve should lead or slightly precede the vertical curve. The vertical curve (especially in sag) should never be significantly longer than the horizontal.

With regards to the study of road perspectives (Brummelaar 1983) cited that the roundness of the reversal curve on the edge of the road is an important clue to the driver when approaching the bend. (See Figure 4). The curve can be seen as 'open' or 'closed' depending on the sharpness of the reversal curve. The form of the reversal curve is dependent on the radius of the curve and the road width. As shown in Figure 1b, the road picture does not form a sharp reversal point which allows the driver to draw conclusions and take action accordingly. As the driver moves towards the curve approaching the sharp reversal point, the point slowly changes to a rounded form (the reversal curve) shown in Figure 1a. The reversal curve gives some indication of curvature to the driver. Drivers determine their expected speed-driving behaviour for an oncoming curve by the visual shape of the reversal point formed at the edge of the road.

The formula below indicates that, at the approach distance (Z), the curve appears to be 'open'(Brumelaar 1983).

$$Z = R^2 (46h-2a)$$

Where: R = Radius of the curve (m).
h = Height of the observers eye (m).
a = Distance of the observer to the road edge.

See also Figure 4.

This means that the wider the road is, the shorter the critical approach length will be.

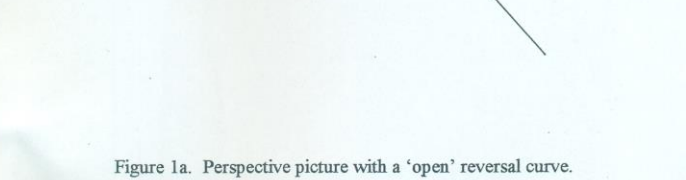


Figure 1a. Perspective picture with a 'open' reversal curve.

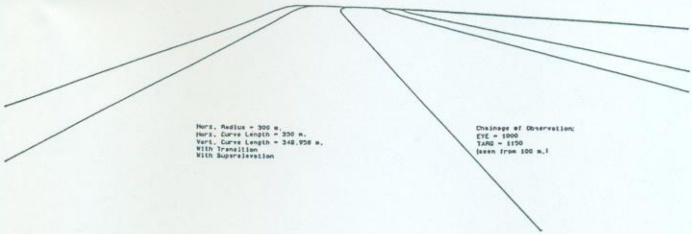


Figure 1b. Perspective picture with 'closed' reversal curve.

Any curve when seen from a long distance in perspective looks like a sudden change in direction on the road, a *kink*. A kink does becomes more open if the viewing distance is shorter. This is also true for plan curves with large radii if they are observed from a far distance. The kink does not give good guidance to the driver. So, it is necessary to assess the critical viewing distance, allowing the driver to see no kink while providing him enough time in preparing to negotiate the curve. The perspective with shorter approach distance to the clearly visible kink was chosen as the critical condition. As pointed out in Figure 2, the critical condition proposed by (Brummelaar 1975) has an angle between two asymtotes of hyperbola of 2.5 degrees. The curve will be observed as open when the angle is more than 2.5 degrees.

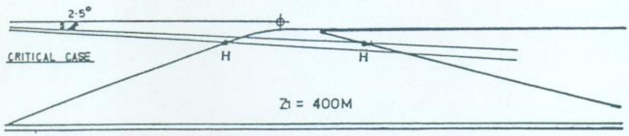


Figure 2 Perspective of critical case

2. EXPERIMENTAL METHODS OF ROAD PERSPECTIVE DRAWINGS

2.1 Description of Road Perspective Drawing Measurement

As discussed by (Brummelaar 1975, 1983 and 1991), the edge of curves in perspective is an important clue to the driver. A curve looks 'open' when a portion of the pavement of the road is visible some distance beyond the reversal point. When the curve looks 'closed' the driver may not have enough time to adjust his speed to the requirements of the curve. The roundness of the reversal curve has a major influence on the behaviour of the driver. When the reversal of the road edgeline on the perspective is a sharp change in direction, then the driver does not have any information on what curvature to expect. The reversal curve denotes how much of the curve can be seen by the driver from a far distance. See pictures in Figure 3.

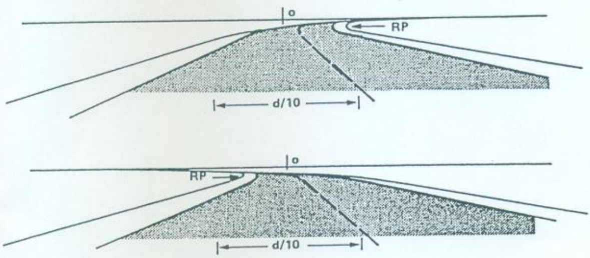


Figure 3. Position of Reversal curves in perspective .

Observation should view the picture from a point perpendicular above the picture origin O at a distance of d.

2.2 Execution or Calculation of Road Perspective Drawing Using MOSS Program

The perspective are all computer-generated line drawings representing the edges and the centerline of a road. The perspective viewpoint is the normal viewing position of a driver in an automobile positioned in the left-hand lane of a 2 lane-2way rural highway with a 1.15 meters eye height.

In this experiment the design speed used for all curves was 100 km/hr which is suitable to most rural highways. The geometry of the horizontal alignment is a two-lane, two-way road with a width of 3.5 meters per lane and side shoulders of 1.5 meters. The traffic lane and the shoulder have a crossfall of 3.5% and 4.5% respectively. As well as, a superelevation of 6% and 60 meters long spiral transition. The upgrade and downgrade values of crest curve are equivalent to 6%. Other informations of road elements are shown in Table 1.

Table 1 Information of Road Elements

Horizontal Radius (m)	Horizontal Curve Length(m)	Vertical Curve Length(m)	Length of Tangent (before the curve, m)	Length of Tangent (after the curve, m)
300	350	349.956	1100	750
800	950	950.118	750	500
1400	1650	1650.619	350	200

Plan transition length is provided sufficient to the superelevation development for the rate of rotation of the pavement of 0.025 rad/sec of travel time at the design speed. However, where a transition is desired for appearance purposes, the length is also sufficient to a shift of more than 0.25 meter. In this study the perspective drawings were created with and without plan transition.

There were two MOSS input files employed in this experiment. One created a road model and the other produced a perspective drawing. Once the original input file was created, some data in the file had to be changed to produce the other set of drawings. These include the minimum, median and maximum horizontal curves and the requirements of transition and superelevation (with or without conditions). Likewise for perspective drawings, alterations were made to EYE and TARGET positions.

1. *Road Model Input File* (See attached copy of sample input file)
The horizontal alignment major HALGN allowed the creation of a straight (tangent) road and a road with variations of radius curves (300, 800 and 1400 meters) connected by a transition of 60 meters long. A masterstring has been used to define the centerline of the horizontal alignment. MOSS differentiates between FIXED, FLOATING and FREE geometric elements which are given in the straight and curve input data. Minor 300 specifies some general facts about the alignment. The fields were indicated by labels rather than numbers and some of the labels have default values. Chainage points were created at 50 meters interval by minor 300. Minor 301 was supplied for each geometric element and labels were used to indicate the fields. Examples of minor 301 are coordinates of chainage points along the centerline, the radius and the length of leading and trailing transitions.

The elevation on the chainage points of the masterstring was calculated by the vertical alignment major VALGN. The method of VALGN also used the theory for application of FIXED, FLOATING and FREE elements. All elements of curves were considered in VALGN with a parameter M. M is related to K-value which is used by NAASRA design policy (See Table 2 for M and K values of crest curve). The upgrade and downgrade values of crest curve are equivalent to 6%. Computation M and K values as follows:

$$K = L/A$$

Where: K = length required for 1% change of grade
L = length of vertical curve
A = change of grade % (12%)

$$M = 100/K$$

-ve for crest
+ve for sag

Table 2 M and K values of crest curve

Radius (m)	K-value (m)	M-value (m)
300	29.163	-3.429
800	79.176	-1.263
1400	137.552	-0.727

In DESIGN, the road formation was generated with and without superelevation. The masterstring was used as a reference string delineating the sides and edges of the road information. Superelevation was obtained by raising or lowering the road edge string in the curve. The major DESIGN was used to generate the new strings. Minor 100 created new strings offset at constant slope and distance from the reference string. Minor 132 was used for gradual vertical change while minor 130 was used for constant vertical changes.

2. *Perspective Drawing File* (see attached copy of sample input file)
The perspectives were produced from the string stored in the road model. The true pictures were produced by defining the EYE and TARGET position (defining the direction of the principal axis). Perspectives were drawn in EYE-TARGET distance 25 times the width of the road. To produce a perspective picture it is necessary to create a new model, which contains the strings of the road pavement model transformed to the two dimensional coordinates of the perspective. This was done by major VIEW.
Example :
VIEW, CURVE
VIEW, PERS
Minor 920 was used in setting the paper while minor 921 defined the EYE and Target positions. Perspective drawings were done using the macro PLANDRAW for a viewing distance of 0.5 meter as the scale was set at 2. Futhermore, a .dpf file was created to draw a model using the major DRAW.

With the above mentioned files, a total of 72 perspective drawings were completed from the three different observation distances to the Tangent Point (TP) (See volume of perspective drawings).

300 Meters observation distance represents 10.8 seconds driving at 100 km/hr (200 meters = 7.2 seconds, 100 meters = 3.6 seconds).

2.3 Observation

All perspective drawings have been produced using the MOSS program. The execution of this program was carried out on Apollo workstations, Department of Civil Engineering, University of New South Wales, Australia. A series of perspective drawings of a road curve were generated with the observers different viewing distances from the curve tangent point. For each drawing an evaluation was made on whether the curve was visible as 'open' or 'closed'. It was derived from the perspective drawings (refer to appendices) according to four categories, namely: 1) both with transition and superelevation; 2) with transition and without superelevation; 3) without transition and with superelevation; 4) both without transition and superelevation. (Evaluations of perspective drawings of different radii are shown in Tables 3a, 3b and 3c). Moreover, all horizontal curves were combined with vertical curves of equal length between 6% grades.

1. Minimum Radius = 300 meters (Table 3a)

In all categories, the left-hand side curves were 'open' from a distance of 100 meters, while the curves seen from 200 and 300 meters do not give information to the driver. Curves on the right-hand side were 'closed' from all points of observations. This could possibly be unwanted situation.

2. Median Radius = 800 meters (Table 3b)

The left-hand side curves were 'open' from the distance of 100 and 200 meters, whereas curves seen from 300 were 'closed' in all categories. The right-hand side curves were considered as 'open' from the distance of 100 meters in categories 1 and 3. Other curves were seen as 'closed'.

3. Maximum Radius = 1400 meters (Table 3c)

Curves on the left-hand side were seen as 'open' from the distance of 100 and 200 meters in all categories, while the curve viewed from 300 meters were also regarded as 'open' in categories 1 and 3 and 'closed' in categories 2 and 4. The right-hand side curves were observed 'open' from the distance of 100 meters, while the other points of observation were 'closed' in all categories.

3. DISCUSSION OF STUDY RESULTS

The results are discussed according to the effect of the variables of curve radius, viewing distance, superelevation and transition. This will be followed by the consideration of simple and more complex combinations of variables. Since the view of the curves were not from the center of the road, it is most likely that the perceived curvature would differ for the right-hand and left-hand curves.

Effect of Radius

The effect of radius of curvature was found to be significant, that is, radius was seen as the main determinant for curvature judgment. Curves with three different radii were studied and viewed from different approach distances.

1.) Curve to the left (Refers table 3c and perspective drawings in appendix)

At approach distance of 100 meters all curves are 'open' and at the approach distance of 300 meters only the 1400 meters radius with superelevation is 'open'. The perspective confirms that curves with larger radii, even on crest provide better/earlier information to the drivers.

2.) Curve to the right (See Attached appendices)

At approach distance of 100 meters only the superelevated 800 meters radius and all the 1400 meters radius curves are 'open'. At 300 meters all curves are still 'closed'. The curve to the right appears to provide less information and later to the driver. It therefore, appears that curves with large edge distances provide less information on crests than curves with short edge distances. Other effects which may be noted are the small radius curve in combination with a small length crest curve which shows only a very small section of the pavement before the crest. Even at 100 meters approach distance, drivers do not get a very good view of the crest curve and they might be wondering about possible limitations in Sight Distance. This is not the case for the larger radii curves. (See drawings in the appendices).

Effect of Transition

Transition length of 60 meters are provided before and after the bend on the different radii curves. The presence of the transition curve does not provide the driver with an open curve at a larger approach distance. Curves with transitions however have clearly a larger 'origin distance' which must assist the driver as it makes the beginning of the curve look as if it has a larger radius. The 'origin distance' of 800 meters and 1400 meters curve radii appears longer at the approach distance of 100 meters and 200 meters. For 300 meters radius, curve has a longer 'origin distance' at 100 meters approach distance. Therefore, transition gives a larger origin distance of the reversal curve more significantly to smaller radius curve. This provides safer speed adjustment of vehicles before and after the curve.

Effect of Superelevation

A 6% superelevation is applied to bends by raising the outer pavement edge along the spiral transition curve. For 300 meters radius curves it appears that the 'openess distance' is larger for curves with superelevation (both to the left and to the right). For 800 meters radius curve this pattern is repeated as it is for 1400 meters radius curves. The approach distance at which the curve is seen as 'open' also is larger for superelevated curves. (Note 800 meters Right at 100 meters approach and 1400 meters Left at 300 meters approach) Superelevation therefore not only improves the riding quality but also the visual information provided by the curve.

Effect of Radius with Transition

In this study, the effect of small radius curves gives a longer origin distance of reversal curve. Transition in larger radii curves are effective for appearance purposes of the curve including also the smaller radius curves. Therefore, it is essential to provide a transition to smaller radius than to a larger radii for safety and comfort to drivers.

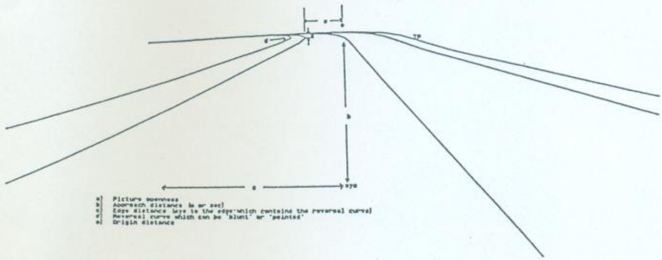
Effect of Radius with Superelevation

The appearance of the perspective drawing shows that smaller radius with superelevation improves the visual information to the driver when entering that curve from the approach distance. Larger radii with superelevation give more 'blunt' reversal curve. It is concluded that smaller radius must be provided with superelevation to have a longer reversal curve distance and shows a pleasing visual effect. (See drawings of with and without superelevation in the appendices)

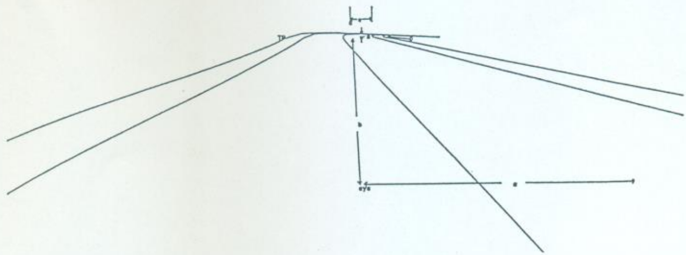
Effect of Radius with Transition with Superelevation

The effect of radius with transition and superelevation shows a more pleasing appearance of the reversal curve specifically to smaller radius. The curve appears more effective visually to smaller radius than to large radii. The importance of transition and superelevation in a large radii has a little effect to the reversal curve. While the reversal curve of small radius looks more 'blunt' to the driver from the approach distance. It is concluded that transition and superelevation to the different radii provide a better, more informative picture of the road ahead.

As mentioned in the previous chapter, the openess of the reversal curve is determined by measuring the distance between the edge of the pavement and the reversal curve above the reversal curve. Illustration is shown in Figure 4. The 'roundness' and 'pointiness' of the reversal curve are important clues to the driver's point of view when approaching the bend. When the openess distance is equal to or larger than 2 mm (0.002 meters) the curve is open. If the distance is less than 2 mm then the curve is closed. If the curve is closed then the driver has no information about the curve and as a result may no longer drive in relaxed manner.



a) Left-hand curve



b) Right-hand curve

Figure 4 Typical reversal curve

5. CONCLUSION

Perspective drawings should be based on the driver's position when driving in order that the drawing can be evaluated in accordance with the drivers perception. Perspective drawings are produced and measurements are conducted to compare the three different radius curves according to the effect of 'with' and 'without' transition and 'with and without' superelevation. It was found out from the results of the pictures that the reversal curve distance is dependent on the curve radius and the approach distance. Curves to the

left appear to be 'open' at the greater distance to the curve entry. Thus, it is generally judged more visuallly informative to the drivers. Whereas, curve to the right is considered less informative to the driver. It seems that larger edge distances produce curve pictures which provide the driver with better information before approaching the bend. Moreover, curves with larger radii, even on crest provides more visual information to the drivers.
The presence of the transition has a significant effect to smaller radius curves which gives a larger 'origin distance' of the reversal curve. Still, this effect is less informative at a larger approach distance. Transition does not provide the driver with an open curve at a larger approach distance.

Curves with superelevation improves the riding quality and shows a pleasing visual effect to the curve. Smaller radius appears that the 'openess distance' is larger when the curve is superelevated. Moreover, the provision of superelevation on curves increases the distance over which the curve is seen as open. Thus, it gives the best visual appearance to the curve.

The effect of a short crest, limits the visibility of the reversal curve from a greater approach distance. While a larger crest provides the driver with sufficient information of the reversal curve when approaching the bend.

Perspective drawings can be used effectively for road design evaluation if the design will be provided with more cues, so that the driver will not misjudge the severity of the curvature.

Therefore, a well-designed road should contribute not only to the safety of road users but it should also present an aesthetically satisfying and pleasing pictures.

It is recommended that further study on perspective drawings of the different grade slopes will be generated to improve the design guidelines or supplementary to this undertaking.

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Sample Model Input Files

1. Model Input File

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CREATE,CURVE

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301,2RE,RA=300.,L1=60.,T1=60.
301,3,SX,X1=2400.,Y1=2400.,X2=3000.,Y2=900
999

VALGN,CURVE
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999

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2. Perspective Drawing File

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CREA,PERS

VIEW,CURVE
VIEW,PERS
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Table 3 Measurement of Perspective Drawing

Table 3a Minimum Horizontal Radius (300 meters)
Lenght of Vertical Curve = 349.959 m. between two 6% grades

Points View to Tangent T.P. (m)	With Transition With Superelevation			With Transition Without Superelevation		
	Curve Appearance	Description of Reversal Curve	Pavement Visible Above Reversal Point (m)	Curve Appearance	Description of Reversal Curve	Pavement Visible Above Reversal Point (m)
Curve to the Left						
100	Open	Rounded	0.015	Open	Rounded	0.004
200	Closed	Slightly Rounded	-	Closed	Slightly Rounded	-
300	Closed	Pointed	-	Closed	Pointed	-
Curve to the Right						
100	Closed	Slightly Rounded	-	Closed	Slightly Pointed	-
200	Closed	Pointed	-	Closed	Pointed	-
300	Closed	Sharply Pointed	-	Closed	Sharply Pointed	-

Points View to Tangent T.P. (m)	Without Transition With Superelevation			Without Transition Without Superelevation		
	Curve Appearance	Description of Reversal Curve	Pavement Visible Above Reversal Point (m)	Curve Appearance	Description of Reversal Curve	Pavement Visible Above Reversal Point (m)
Curve to the Left						
100	Open	Rounded	0.01	Open	Rounded	0.005
200	Closed	Slightly Rounded	-	Closed	Slightly Rounded	-
300	Closed	Pointed	-	Closed	Pointed	-
Curve to the Right						
100	Closed	Slightly Rounded	-	Closed	Slightly Pointed	-
200	Closed	Pointed	-	Closed	Pointed	-
300	Closed	Sharply Pointed	-	Closed	Sharply Pointed	-

Table 3 Measurement of Perspective Drawing

Table 3b Median Horizontal Radius (800 meters)
Length of vertical Curve = 950.118 m. between two 6% grades

Points View to Tangent T.P. (m)	With Transition With Superelevation			With Transition Without Superelevation		
	Curve Appear-ance	Descrip-tion of Reversal Curve	Pavement Visible Above Reversal Point (m)	Curve Appear-ance	Descrip-tion of Reversal Curve	Pavement Visible Above Reversal Point (m)
Curve to the Left						
100	Open	Rounded	0.015	Open	Rounded	0.008
200	Open	Slightly Rounded	0.003	Open	Slightly Rounded	0.002
300	Closed	Slightly Pointed	-	Closed	Slightly Pointed	-
Curve to the Right						
100	Open	Slightly Rounded	0.002	Closed	Slightly Pointed	-
200	Closed	Pointed	-	Closed	Pointed	-
300	Closed	Sharply Pointed	-	Closed	Sharply Pointed	-

Points View to Tangent T.P. (m)	Without Transition With Superelevation			Without Transition Without Superelevation		
	Curve Appear-ance	Descrip-tion of Reversal Curve	Pavement Visible Above Reversal Point (m)	Curve Appear-ance	Descrip-tion of Reversal Curve	Pavement Visible Above Reversal Point (m)
Curve to the Left						
100	Open	Rounded	0.015	Open	Rounded	0.01
200	Open	Slightly Rounded	0.003	Open	Slightly Rounded	0.002
300	Closed	Slightly Pointed	-	Closed	Slightly Pointed	-
Curve to the Right						
100	Open	Slightly Rounded	0.002	Closed	Slightly Pointed	-
200	Closed	Pointed	-	Closed	Pointed	-
300	Closed	Sharply Pointed	-	Closed	Sharply Pointed	-

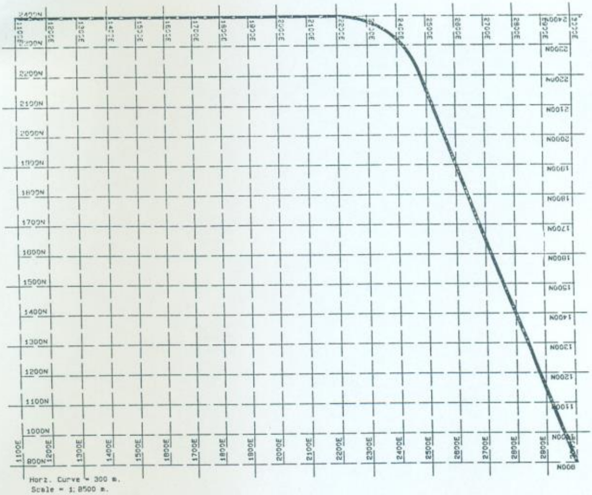


Figure 5 Horizontal Alignment (Radius = 300 m.)

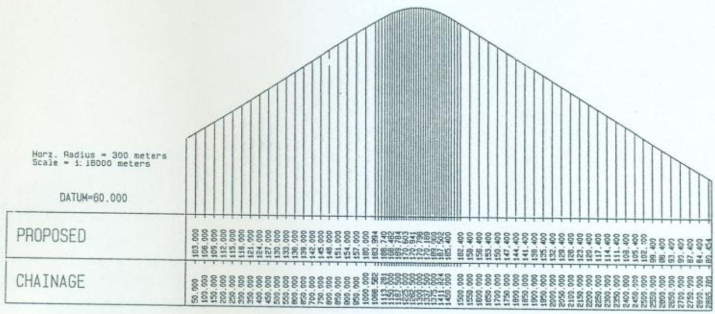


Figure 6 Vertical Alignment (Radius = 300 m.)

Table 3 Measurement of Perspective Drawing

Table 3c Maximum Horizontal Radius (1400 meters)
Length of Vertical Curve = 1650.619 m. between two 6% grades

Points View to Tangent T.P. (m)	With Transition With Superelevation			With Transition Without Superelevation		
	Curve Appear-ance	Descrip-tion of Reversal Curve	Pavement Visible Above Reversal Point (m)	Curve Appear-ance	Descrip-tion of Reversal Curve	Pavement Visible Above Reversal Point (m)
Curve to the Left						
100	Open	Rounded	0.02	Open	Rounded	0.01
200	Open	Slightly Rounded	0.01	Open	Slightly Rounded	0.005
300	Open	Slightly Pointed	- 0.003	Closed	Slightly Pointed	-
Curve to the Right						
100	Open	Rounded	0.005	Open	Rounded	0.002
200	Closed	Slightly Pointed	-	Closed	Slightly Pointed	-
300	Closed	Pointed	-	Closed	Pointed	-

Points View to Tangent T.P. (m)	Without Transition With Superelevation			Without Transition Without Superelevation		
	Curve Appear-ance	Descrip-tion of Reversal Curve	Pavement Visible Above Reversal Point (m)	Curve Appear-ance	Descrip-tion of Reversal Curve	Pavement Visible Above Reversal Point (m)
Curve to the Left						
100	Open	Rounded	0.02	Open	Rounded	0.012
200	Open	Slightly Rounded	0.01	Open	Slightly Rounded	0.005
300	Open	Slightly Pointed	0.003	Closed	Slightly Pointed	-
Curve to the Right						
100	Open	Rounded	0.005	Open	Rounded	0.003
200	Closed	Slightly Pointed	-	Closed	Slightly Pointed	-
300	Closed	Pointed	-	Closed	Pointed	-

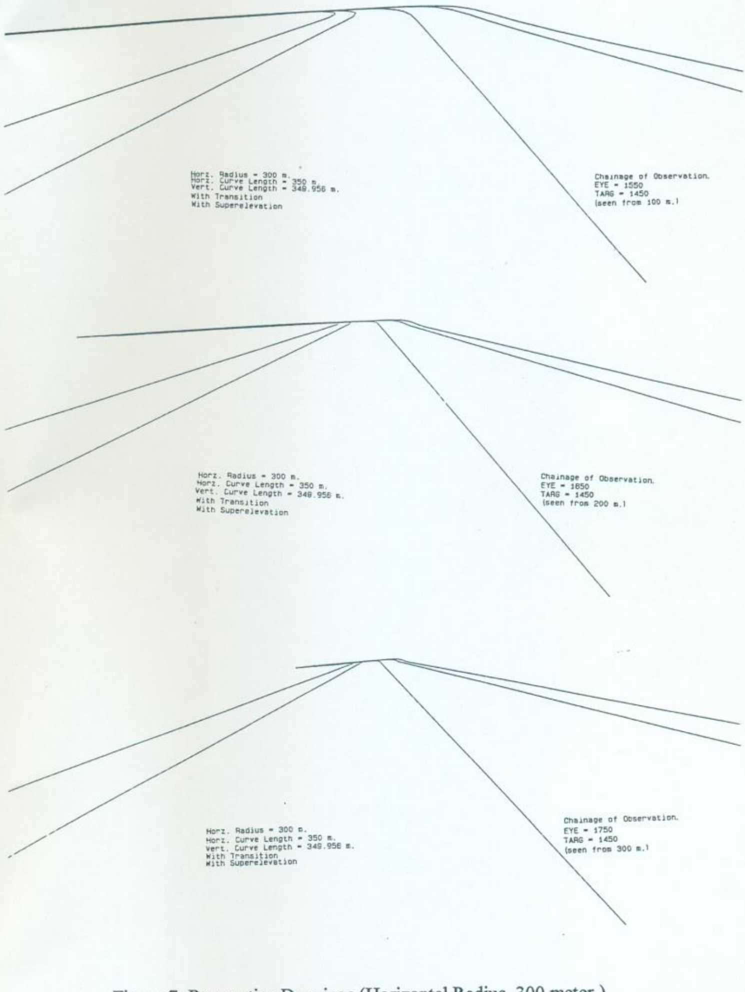


Figure 7 Perspective Drawings (Horizontal Radius 300 meter.)
Left Curve (Seen from the distance the of 100, 200 and 300 meters)
With Transition and With Superelevation

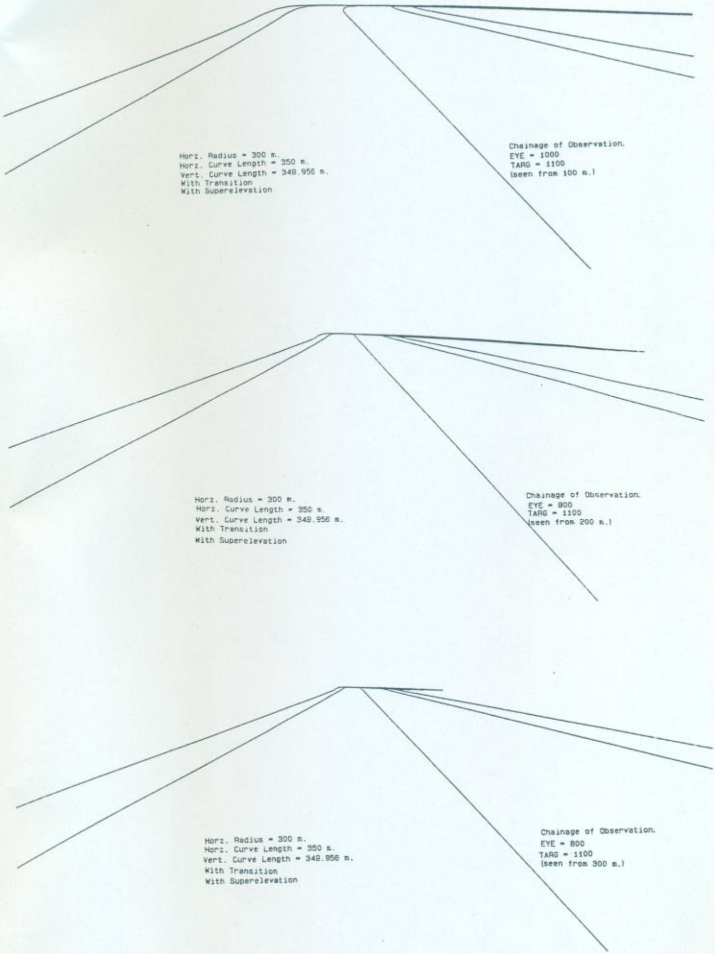
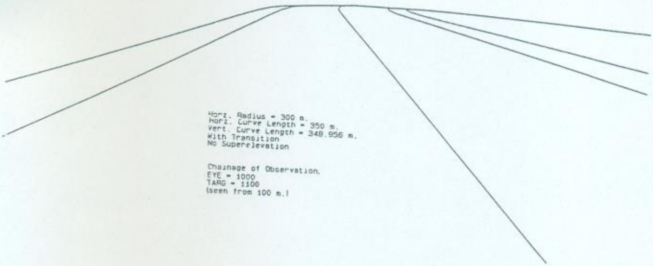
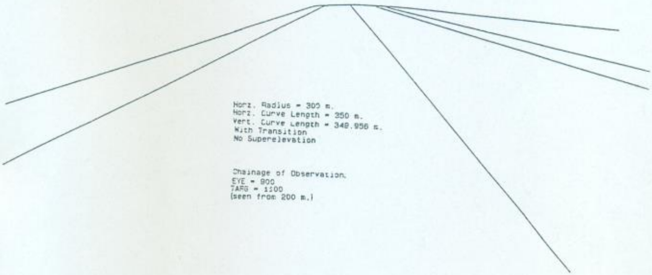


Figure 8 Perspective Drawings (Horizontal Radius 300 meter.)
Right Curve (Seen from the distance the of 100, 200 and 300 meters)
With Transition and With Superelevation





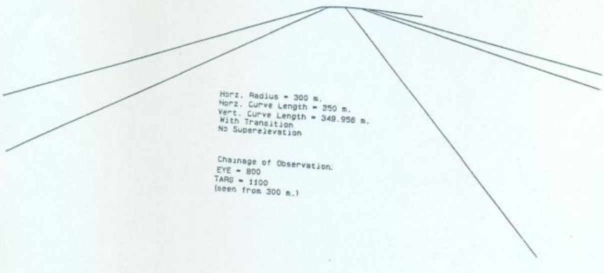
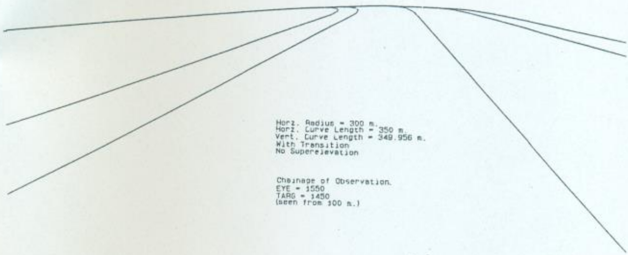
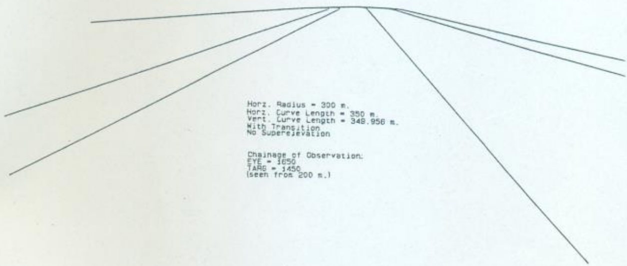


Figure 10 Perspective Drawings (Horizontal Radius 300 meter.)
Right Curve (Seen from the distance the of 100, 200 and 300 meters)
With Transition and No Superelevation





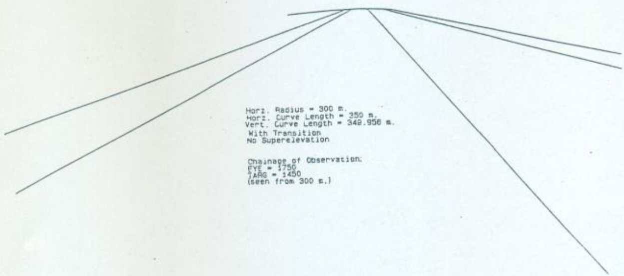


Figure 9 Perspective Drawings (Horizontal Radius 300 meter.)
Left Curve (Seen from the distance the of 100, 200 and 300 meters)
With Transition and No Superelevation

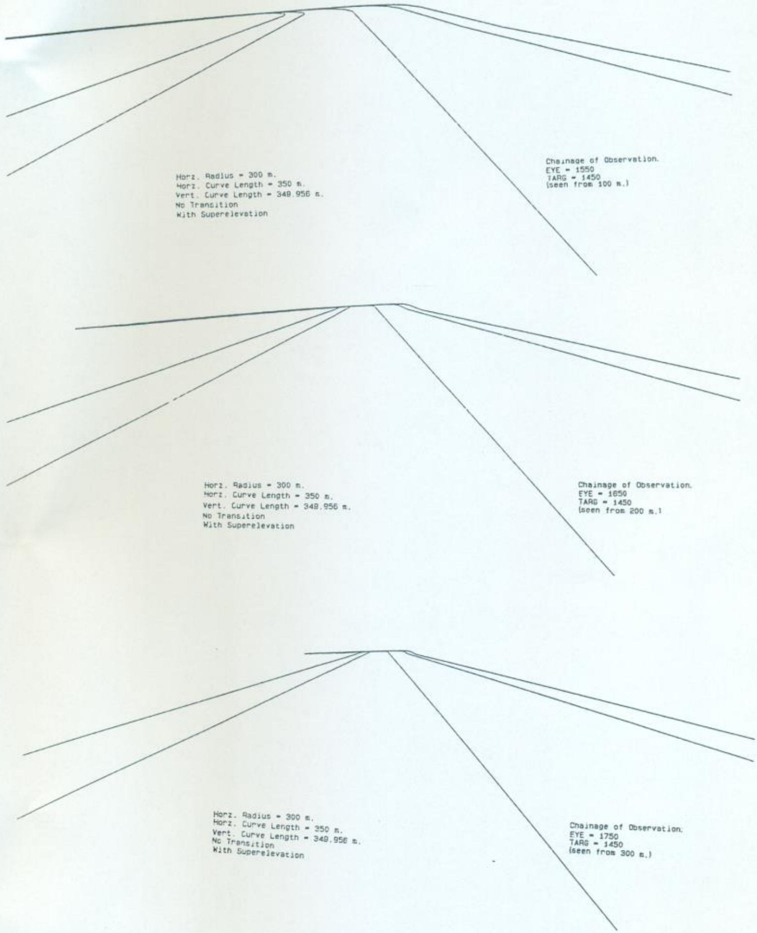


Figure 11 Perspective Drawings (Horizontal Radius 300 meter.)
Left Curve (Seen from the distance the of 100, 200 and 300 meters)
No Transition and With Superelevation

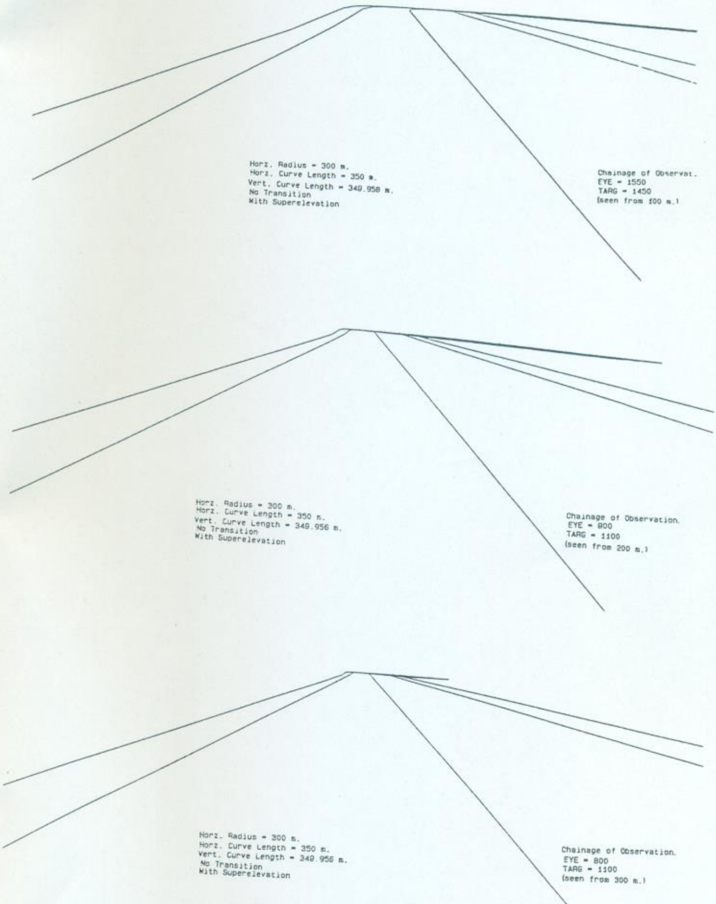


Figure 12 Perspective Drawings (Horizontal Radius 300 meter.)
Right Curve (Seen from the distance the of 100, 200 and 300 meters)
No Transition and With Superelevation

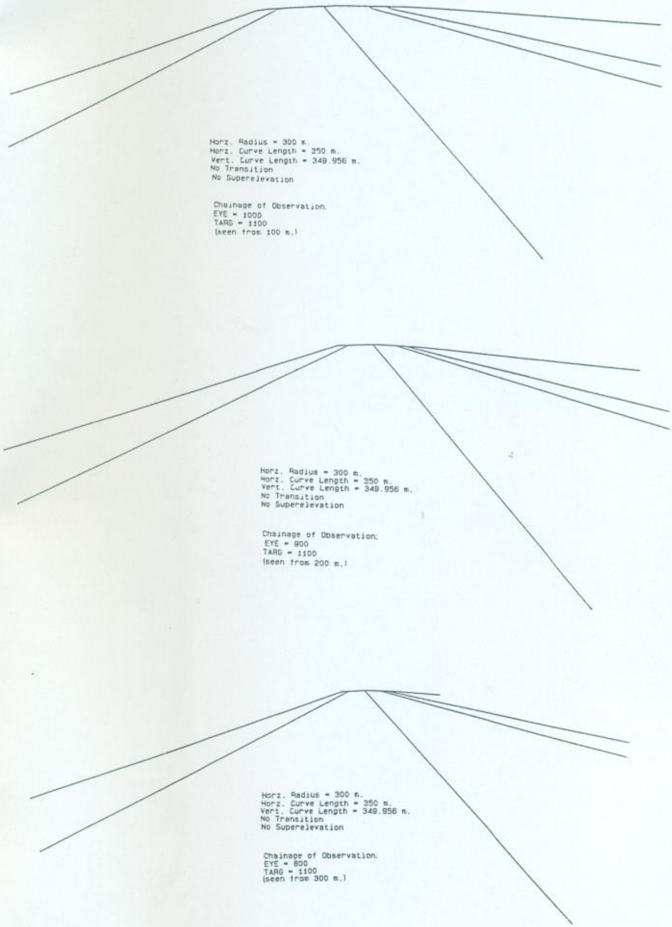


Figure 14 Perspective Drawings (Horizontal Radius 300 meter.)
Right Curve (Seen from the distance the of 100, 200 and 300 meters)
No Transition and No Superelevation

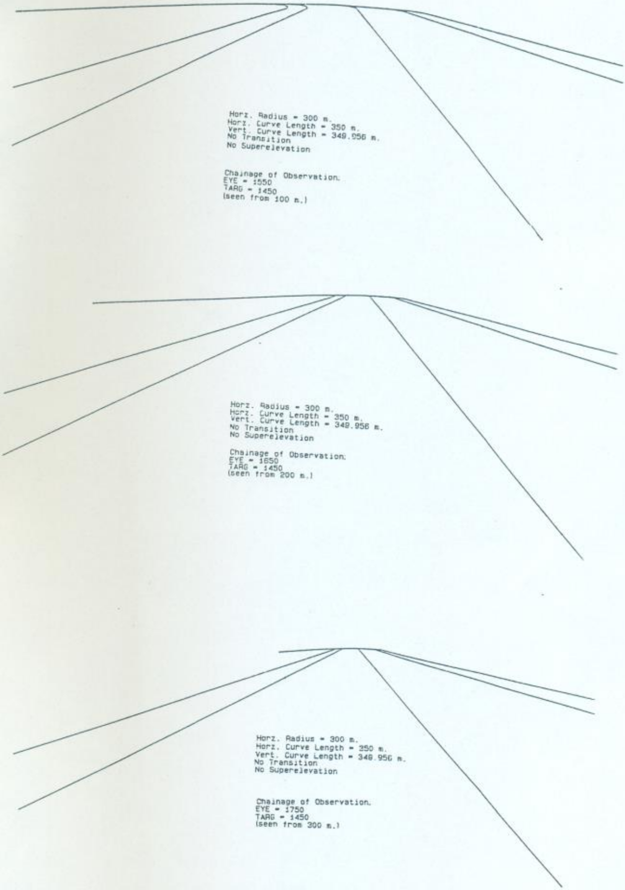


Figure 13 Perspective Drawings (Horizontal Radius 300 meter.)
Left Curve (Seen from the distance the of 100, 200 and 300 meters)
No Transition and No Superelevation