DEVELOPMENT OF HIGHWAY HORIZONTAL ALIGNMENT ANALYSIS ALGORITHM APPLICABLE TO THE ROAD SAFETY SURVEY AND ANALYSIS VEHICLE, ROSSAV

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Abstract: In this research, the horizontal alignment analysis algorithm was developed which can recognize the highway sections whether they are tangent sections or curve sections using the real world coordinate data. The proposed algorithm for horizontal curve analysis includes the identification of beginning and ending points of horizontal curves for the circular and transition curves, the parameter of clothoid, radius of circular curve, and length of circular and transition curves. The calculated coordinates for the beginning of curve, beginning of tangency, values for the radius, length of curve, clothoid parameter, and central angle show almost similar to the real world coordinates and real world values. The analysis algorithm of horizontal curves expects to be used as a basis of automatic procedure which can identify the highway deficient sections along the highway route and analyze highway safety in terms of quantitative measures.

Key Words: Horizontal Curve, Highway Safety, GPS, INS, CCD

1. INTRODUCTION

In order to evaluate highway safety, it is essential to have highway geometric information such as horizontal alignments, vertical alignments, and cross section information. Most analyses of geometric alignments have been done using the highway drawings. In many cases, however highway drawings are not always available and they are inconvenient to be used for the analysis of a long highway section along the route since the highway drawings are usually made for a certain short distance such as 500m, 800m, and so on.

For these reasons, the RoSSAV(Road Safety Survey and Analysis Vehicle) has been developed in order to collect highway geometric information and to analyze the highway sections along the highway route. Multiple sensors were installed to collect highway geometric information such as GPS(Global Positioning System), IMU(Inertial Measurement Unit), DMI(Distance Measuring Instrument) and CCD cameras to acquire real world highway coordinates and attitude data. More sensors like laser scanning sensor are considered to be installed to get more realistic cross sectional data and roadside environment data. Figure 1 shows the RoSSAV.(Yun et al., 2004)

The data from the RoSSAV include real-world position data and orientation data. Since the RoSSAV records simple numerical data, the real world coordinates, which represent GPS antenna location, the coordinate data need to be interpreted into the highway geometric data. In order to use these data to analyze the highway horizontal alignments, first of all, the horizontal alignment analysis algorithm was developed. The purpose of this study is to develop the highway horizontal alignment analysis algorithm which can be applicable directly using the position and orientation data from the RoSSAV in the near future. The identification algorithm includes the identification logic whether the section calculated from the coordinates is tangent or curve section. Once the section is determined as a curve section then it should be determined whether this section is a simple circular curve, a transition curve, or a compound curve. In this study, only simple circular curve and clothoid curve were taken into consideration for the curve section analysis. An identification analysis algorithm for the circular curve and clothoid curve has been developed. The values of highway alignment elements needed for the curve section analysis are the radius of circular curve, length of curve, center point of curve, central angle, and clothoid parameter.

Figure 1. Road Safety Survey and Analysis Vehicle (RoSSAV)

2. HORIZONTAL ALIGNMENT ANALYSIS ALGORITHM

The horizontal alignment analysis algorithm from the coordinates is shown in Figure 2. (Yun et al, 2004)

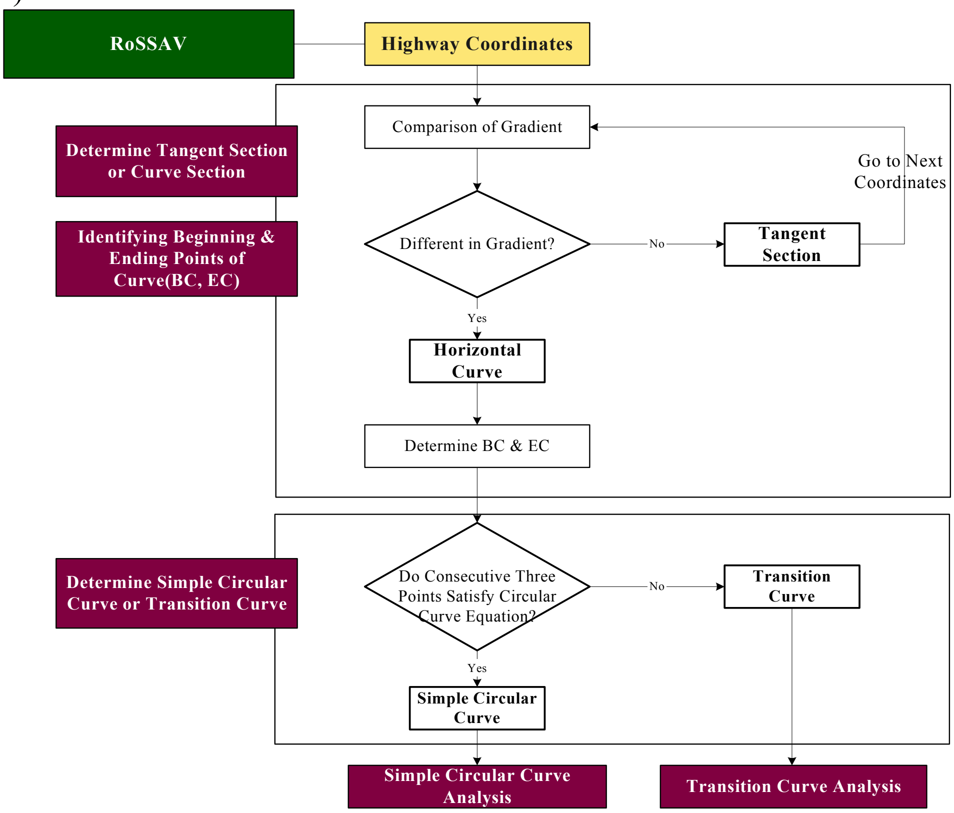


Figure 2. Horizontal Curve Analysis Algorithm

2.1 Analysis of Horizontal Curves

The horizontal alignments are analyzed using the real world highway coordinates. The procedure of horizontal curve analysis from the coordinates is as follows:
1) Identification of tangent section and curve section including beginning and ending points of curve
2) Identification of simple curve and clothoid curve
3) Analysis of geometric information for simple curve and clothoid

1) Analysis of beginning and ending points of horizontal curve

The procedure for determining the tangent and curve sections is made by gradient changing point from the comparison of gradients using two consecutive coordinates. If the gradient becomes changed from the constant gradient, it can be identified that highway section is changed from tangent section to curve section, and if the gradient becomes constant from the changing gradient, then it can be identified that highway section is changed from the curve section to tangent section.

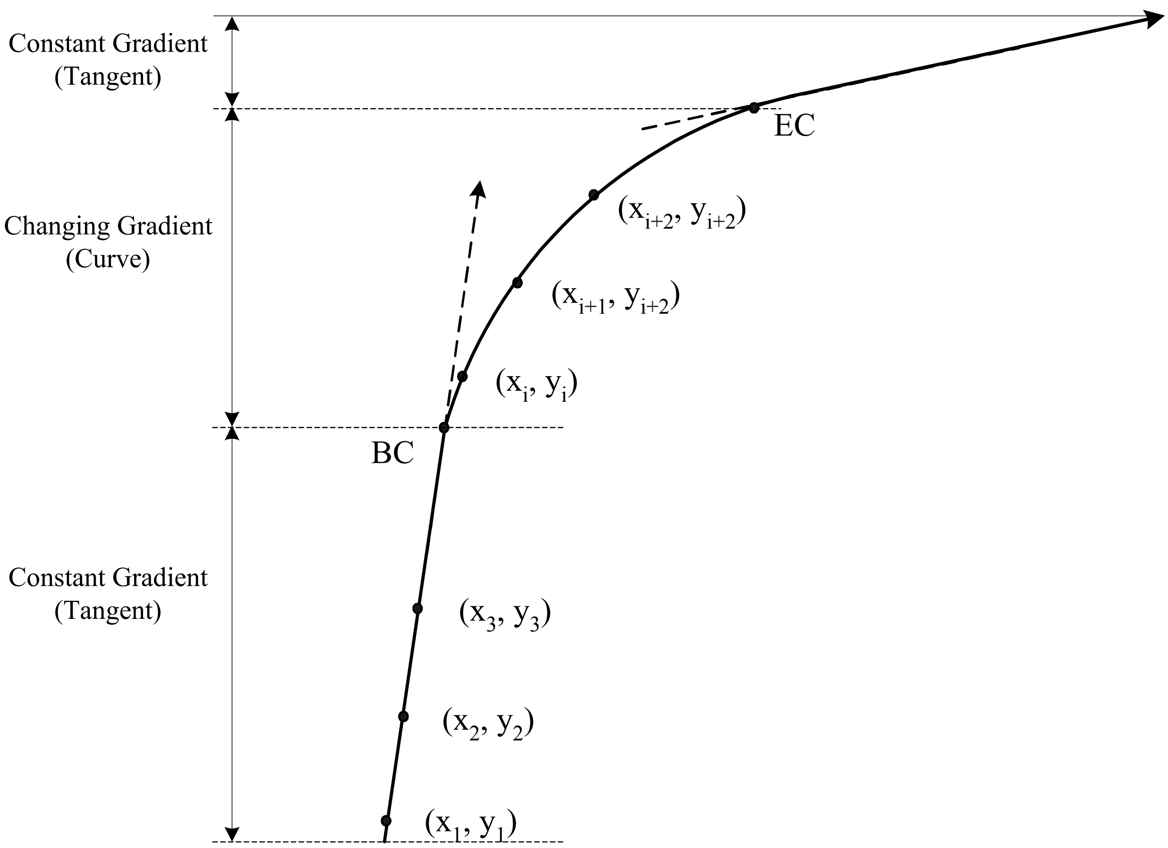


Figure 3. Change of Gradient for Tangent and Curve Section

Figure 3 shows the change of gradient in tangent and curve section. The analysis algorithm for tangent and curve section is as follows.

(a) Calculation of Gradient from the two consecutive coordinates

The gradient for the two consecutive coordinates is calculated using Equation 1.

$$\delta_{2,1} = \frac{(y_2 - y_1)}{(x_2 - x_1)}, \delta_{3,2} = \frac{(y_3 - y_2)}{(x_3 - x_2)}, \cdots\cdots, \delta_{i,i-1} = \frac{(y_i - y_{i-1})}{(x_i - x_{i-1})} \qquad \text{<Equation 1>}$$

where, $\delta_{i,i-1} : (x_{i-1}, y_{i-1}), (x_i, y_i)$: Gradient using two consecutive coordinates

(b) Coordinates (BC and BT) that changes gradient

When two consecutive gradients are compared,

$$\text{If gradient} = \begin{cases} \text{constant and become changed at } \delta_{i,i-1} \\ \quad \rightarrow (x_{i-1}, y_{i-1}) \text{ can be beginning curve(BC)} \\ \text{changing and become constant at } \delta_{i,i-1} \\ \quad \rightarrow (x_{i-1}, y_{i-1}) \text{ can be ending curve(BC)} \end{cases}$$

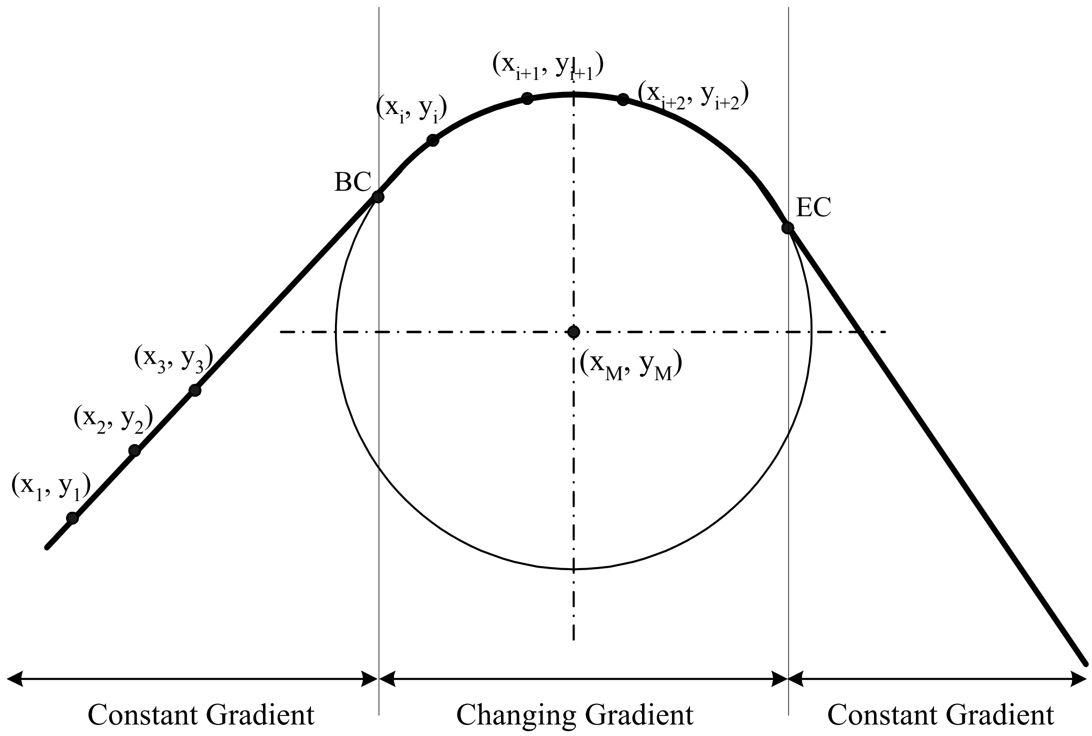


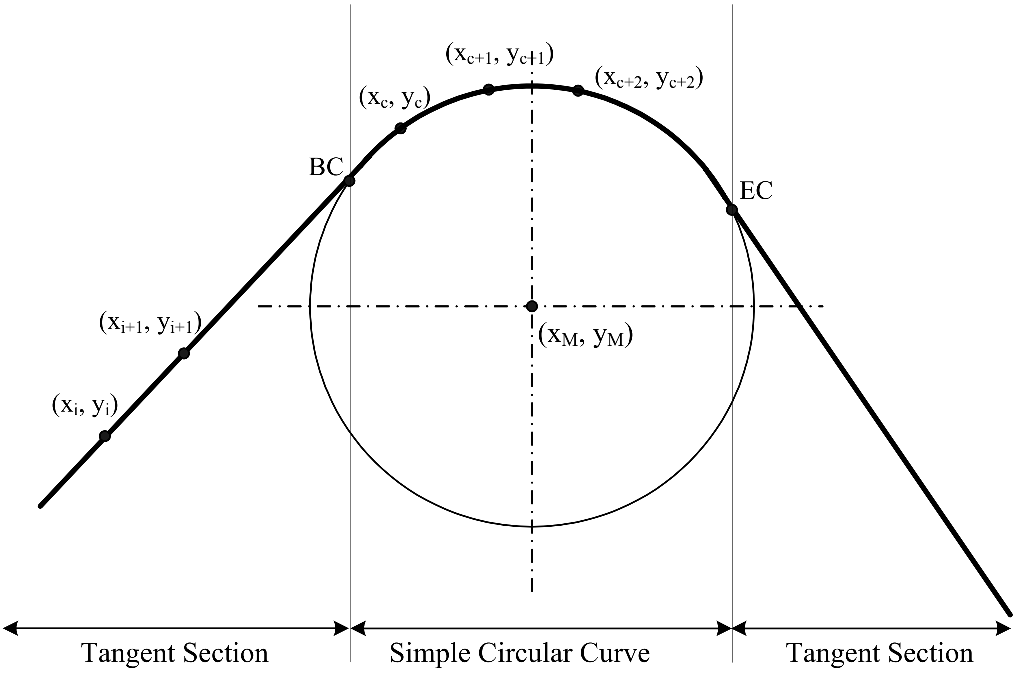
Figure 4. Tangent and Curve Section

2) Identification of Clothoid Curve and Simple Curve

For this study, only simple curve and clothoid curve are considered. Simple curve and Clothoid curve have their own equations and geometric characteristics. Therefore it should be analyzed separately. Once the gradient analysis shows curve section, it is assumed as simple curve. If the simple curve equation is not satisfied, then the curve section becomes clothoid section.

(a) Simple Curve Equation

In order to distinguish clothoid and simple curves by the gradient analysis, once the curve section begins, it is assumed that all the coordinates are satisfied by the simple curve equation. First, all curve sections are assumed as simple curves and all coordinates within curve section satisfy with the simple curve equation as shown in Figure 5.



Where (x_i, y_i), (x_{i+1}, y_{i+1}), i : Coordinate within Tangent Section
(x_c, y_c), (x_{c+1}, y_{c+1}), i : Coordinate within Circular Section

Figure 5. Coordinates within Tangent and Curve Section

Equation 2 shows simple curve equation using the coordinates.

$$(x - x_M)^2 + (y - y_M)^2 = R^2$$ <Equation 2>

where, x_M, y_M: Center of Circle, R : Radius of Circle

(b) Three Consecutive Coordinates on the Curve Section

Using three consecutive coordinates (x_C, y_C), (x_{C+1}, y_{C+1}), (x_{C+2}, y_{C+2}), the center of curve and radius of curve can be calculated by Equation 3, 4 and 5.

$$x_M = \frac{(x_{c+2}^2 + y_{c+2}^2) - (x_c^2 + y_c^2) + \left\{ \dfrac{(x_{c+1}^2 + y_{c+1}^2) - x_2^2 + y_2^2}{(y_{c+1} + y_c)} \right\} (y_c - y_{c+2})}{2\left\{ (x_{c+2} - x_c) + \dfrac{(x_c - x_{c+1})}{(y_{c+1} - y_c)} (y_{c+2} - y_c) \right\}}$$ <Equation3>

$$y_M = \frac{(x_{c+1}^2 + y_{c+1}^2) - (x_c^2 + y_c^2) + 2x_M (x_c - x_{c+1})}{2(y_{c+1} - y_c)}$$ <Equation 4>

$$R = \sqrt{(x_c - x_M)^2 + (y_c - y_M)^2}$$ <Equation 5>

(c) Identification of Clothoid and Simple Curve

In the previous step, the algorithm assumes that the horizontal alignments are composed of tangent and simple curve sections and all coordinates within the curve section satisfy the simple circle equation. In order to satisfy this assumption, any three consecutive coordinates should satisfy the constant numbers for the center of circle *(x_M, y_M)* and radius of circle R from the Equation 3 through Equation 5. If the calculated number of x_M, y_M, and R are not constant from three consecutive coordinates, this curve does not satisfy the simple curve equation and will be considered as a clothoid curve. If the calculated numbers (x_M, y_M, R) are not constant, these coordinates are on the clothoid curve.

Therefore,

$$\frac{(x_{M:C\sim C+2})}{(x_{M:C+1\sim C+3})} \times \frac{(y_{M:C\sim C+2})}{(y_{M:C+1\sim C+3})} \times \frac{R_{C\sim C+2}}{R_{C+1\sim C+3}} = 1$$

$\rightarrow (x_C, y_C) \sim (x_{C+3}, y_{C+3})$ are on the simple curve <Equation 6>

$$\frac{(x_{M:C\sim C+2})}{(x_{M:C+1\sim C+3})} \times \frac{(y_{M:C\sim C+2})}{(y_{M:C+1\sim C+3})} \times \frac{R_{C\sim C+2}}{R_{C+1\sim C+3}} \neq 1$$

$\rightarrow (x_C, y_C) or (x_{C+3}, y_{C+3})$ are on the clothoid curve <Equation 7>

where, $x_{M:C\sim C+2}, y_{M:C\sim C+2}, R_{M:C\sim C+2}$ are x_M, y_M, R three consecutive coordinates on the $(x_C, y_C), (x_{C+1}, y_{C+1}), (x_{C+2}, y_{C+2})$ curve section

If three coordinates $(x_C, y_C), (x_{C+1}, y_{C+1}), (x_{C+2}, y_{C+2})$ all satisfy the simple curve, Equation 6 is satisfied. If any of these three coordinates is not included, Equation 7 will be resulted.

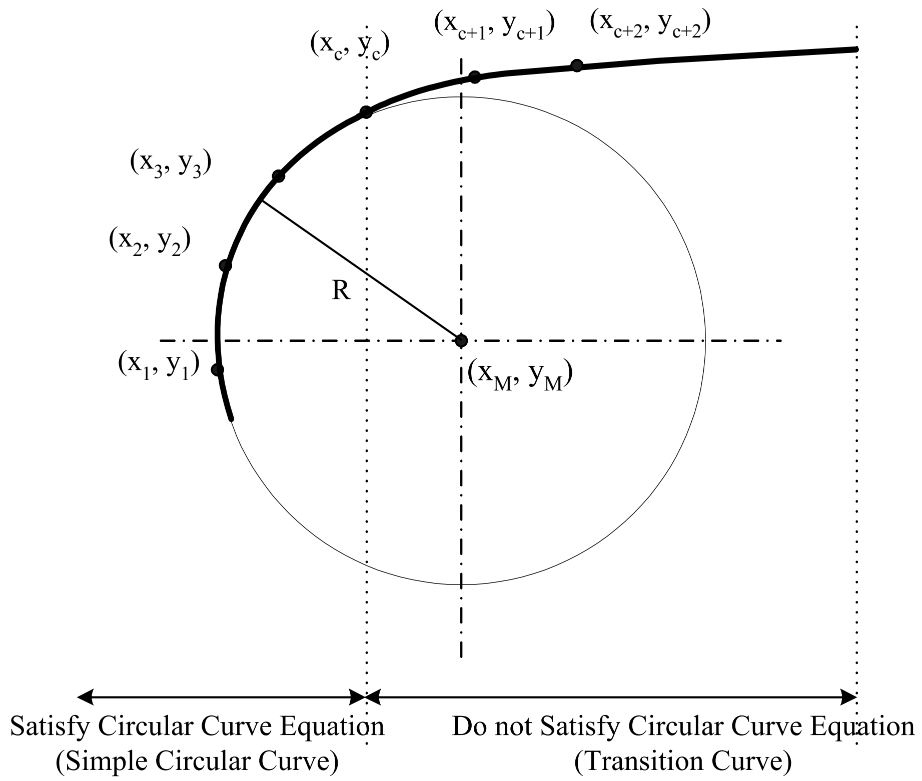


Figure 6. Coordinates within Simple Curve and Clothoid Curve

3) Geometric Information of Simple Curve

Identify simple curve and clothoid curve using Equation 6 and 7, and select coordinates on the simple curve. The center of circle and radius of circle are calculated by the Equation 3 through Equation 5. The length of simple curve and angle ϴ can be calculated as follows. (Hickerson, T., 1964)

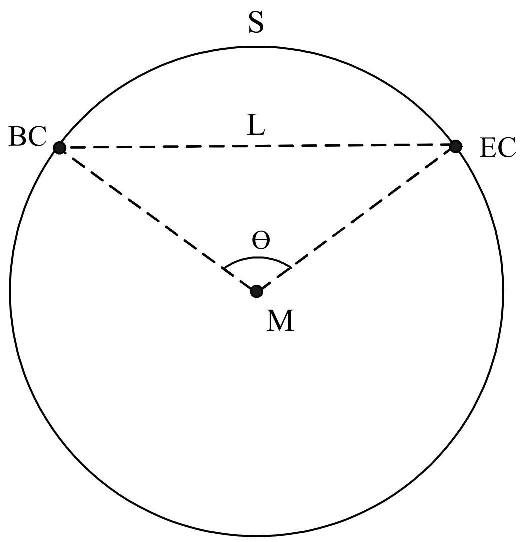


Figure 7. Simple Curve Geometry

a) Calculation of Central Angle ϴ

The coordinates of beginning of curve(BC) and end of curve(EC) are (x_{BC}, y_{BC}) (x_{BC}, y_{BC}).

The length of chord L which connects the beginning of curve and the end of curve can be calculated as follows.

$$L = \sqrt{(x_{BC} - x_{EC})^2 + (y_{BC} - y_{EC})^2}$$ <Equation 8>

The central angle ϴcan be calculated using Equation 9.

$$\sin\left(\frac{\theta}{2}\right) = \frac{L}{2R}$$
$$\theta = 2\sin^{-1}\left(\frac{L}{2R}\right)$$ <Equation 9>

b) Calculation of the Length of Circular Curve S

The length of circular curve S can be calculated by Equation 10 using the radius R and ϴ from the Equation 8 through Equation 9, and L from the Equation 8.

$$\begin{aligned} S &= R \cdot \theta \\ &= R \cdot 2\sin^{-1}\left(\frac{L}{2R}\right) \\ &= R \cdot 2\sin^{-1}\left(\frac{\sqrt{(x_{BC} - x_{EC})^2 + (y_{BC} - y_{EC})^2}}{2R}\right) \end{aligned}$$ <Equation 10>

4) Geometric Information of Clothoid Curve

In this study, only clothoid curve is assumed as transition curve. If a tangent section connects directly to a circular curve, the radius of R abruptly changes from ∞ to constant value and that makes a driver feel uncomfortable. The transition curve can improve smooth driving for the curve section by changing radius of curve from ∞ to constant value smoothly. Therefore the radii of curve are continuously reduced and make the length of clothoid L from the beginning of curve and radius R be inversely proportional.(TAC, 1999)

$L \times R = C$ (constant) <Equation 11>

where L : length of clothoid curve(m)
R : Radius(m)
C : Constant(m^2)

As shown in Figure 8, let two points on the clothoid P_1, P_2, and the length of clothoid curve from the beginning point of curve BTC as P_1, P_2 , then

$L_1 \times R_1 = L_2 \times R_2 = C$ <Equation 12>

The unit of C becomes m^2. If replace $C = A^2$ for the convenience, the equation becomes Equation 13.

$L \times R = A^2$ <Equation 13>

A : parameter of clothoid

The radius at the connecting point of the clothoid curve and circular curve becomes R. The clothoid parameter A can be calculated by Equation 13 using the length of clothoid L and radius of curve R. The length of clothoid curve L from the beginning point BTC to the beginning point of circular curve BC can be calculated using the coordinates.

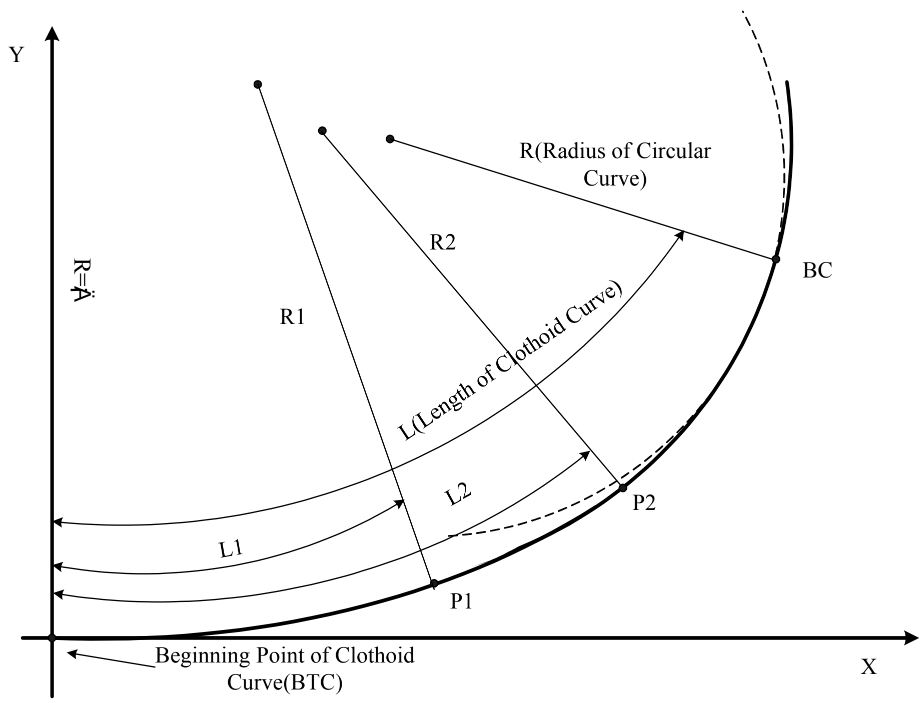


Figure 8. Geometry of Clothoid Curve

3. EXAMPLE OF HORIZONTAL ALIGNMENT ANALYSIS

In order to check the logic from the algorithm, two tests were performed using real world highway CAD drawings in order to apply the algorithm to the RoSSAV,
1) tangent section-clothoid curve section-simple curve section highway alignments and
2) tangent section-simple curve section 1-simple curve section 2- tangent section highway alignments. The developed horizontal alignment analysis algorithm and CAD based drawings were compared by checking the coordinates.

3.1 Simple Horizontal Alignment Case.

Figure 9 shows as an example of highway alignment which composed of 'tangent section(T) -clothoid curve section(BTC)-simple curve(BC)-clothoid curve section(EC) –tangent section(ETC)'.

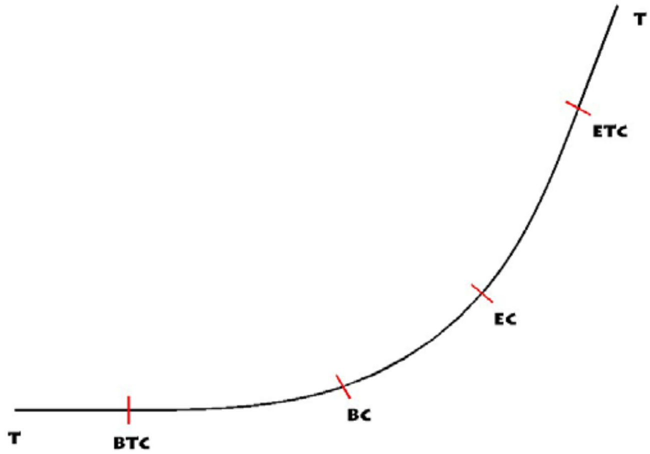
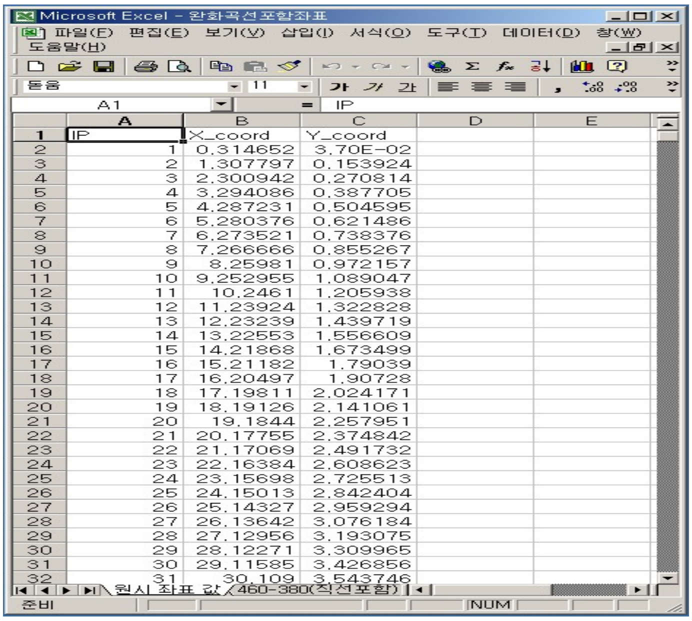


Figure 9. Transition Curve and Simple Circular Curves

The X, Y coordinates for every 1m from the real world highway horizontal alignment CAD drawing are drawn and the coordinates are shown in Figure 10.



	A	B	C	D	E
1	IP	X_coord	Y_coord		
2	1	0.314652	3.70E-02		
3	2	1.307797	0.153924		
4	3	2.300942	0.270814		
5	4	3.294086	0.387705		
6	5	4.287231	0.504595		
7	6	5.280376	0.621486		
8	7	6.273521	0.738376		
9	8	7.266666	0.855267		
10	9	8.25981	0.972157		
11	10	9.252955	1.089047		
12	11	10.2461	1.205938		
13	12	11.23924	1.322828		
14	13	12.23239	1.439719		
15	14	13.22553	1.556609		
16	15	14.21868	1.673499		
17	16	15.21182	1.79039		
18	17	16.20497	1.90728		
19	18	17.19811	2.024171		
20	19	18.19126	2.141061		
21	20	19.1844	2.257951		
22	21	20.17755	2.374842		
23	22	21.17069	2.491732		
24	23	22.16384	2.608623		
25	24	23.15698	2.725513		
26	25	24.15013	2.842404		
27	26	25.14327	2.959294		
28	27	26.13642	3.076184		
29	28	27.12956	3.193075		
30	29	28.12271	3.309965		
31	30	29.11585	3.426856		
32	31	30.109	3.543746		

Figure 10. Coordinates from the Horizontal Alignment CAD Drawing

The results of analysis for the tangent section, transition curve section and simple circular curve sections are shown in Table 1.

Table 1. Coordinates and Horizontal Alignment Analysis

No	x	y	gradient	x_M	y_M	R(m)	section
1	0.314652	3.70E-02					
2	1.307797	0.153924	0.117697	-2.5E+13	2.1E+14	2.12E+14	
3	2.300942	0.270814	0.117697	2.45E+13	-2.1E+14	2.09E+14	
4	3.294086	0.387705	0.117697	-3E+13	2.52E+14	2.53E+14	Tangent Section
5	4.287231	0.504595	0.117697	4.5E+14	-3.8E+15	3.85E+15	- constant gradient
…… omitted……							
165	163.1904	19.20706	0.117697	6.68E+12	-5.7E+13	5.72E+13	
166	164.1835	19.32395	0.117697	-5607.91	49056.93	49376.15	
167	165.1767	19.44084	0.117697	-5680.96	49686.15	50009.59	Clothoid Curve(BTC)
168	166.1698	19.55775	0.117718	-5891.63	51475.62	51811.42	
169	167.163	19.67468	0.117738	-9101.98	78742.22	79266.36	
170	168.1561	19.79163	0.117758	-4477.76	39468.74	39721.58	
171	169.1492	19.90859	0.11777	-3725.51	33085.52	33294.19	
172	170.1424	20.02558	0.117796	-3447.41	30726.1	30918.43	
173	171.1355	20.1426	0.117826	-2648.45	23945.86	24091.29	Clothoid Curve
174	172.1286	20.25965	0.117859	-2176.93	19947.06	20064.78	-changing gradient
…… omitted ……							- changing x_M, y_M, R
477	465.7158	89.00982	0.479651	175.8977	692.0805	669.0955	
478	466.6167	89.44385	0.481766	123.2795	800.9557	790.0187	
479	467.517	89.87922	0.48361	201.3464	639.1138	610.3322	
480	468.4167	90.31573	0.485173	338.2809	357.3956	297.0976	
481	469.3157	90.75371	0.487197	360.4801	313.0031	247.4671	Simple Circular Curve (BC)
482	470.2132	91.1947	0.491354	266.139	505.3908	461.7409	
483	471.1089	91.63932	0.496374	266.139	503.4492	460	
484	472.0036	92.08588	0.499086	266.139	503.4492	460	
485	472.8974	92.53438	0.501805	266.139	503.4492	460	
486	473.7902	92.98482	0.504529	266.139	503.4492	460	Simple Circular Curve
…… omitted ……							
724	649.6329	249.4168	1.506068	266.139	503.4492	460	-changing gradient
725	650.1843	250.2511	1.513196	266.139	503.4492	460	-constant x_M, y_M, R
726	650.7338	251.0866	1.520371	266.139	503.4492	460	
727	651.2815	251.9232	1.527594	266.139	503.4492	460	
728	651.8274	252.7611	1.534865	491.7225	356.4764	190.7628	
729	652.3714	253.6001	1.542185	229.5924	527.1472	503.5575	Simple Circular Curve (EC)
730	652.9111	254.442	1.560003	-58.2378	709.7119	844.3953	
731	653.4491	255.285	1.566857	152.7725	574.2338	593.6374	
732	653.9861	256.1286	1.570959	123.3288	593.3279	628.7293	Clothoid Curve
…… omitted ……							-changing gradient
1042	758.1576	546.4612	4.224667	-28957.9	7579.887	30537.07	- changing x_M, y_M, R
1043	758.3879	547.4343	4.224876	-129017	31263.84	133360.7	
1044	758.6182	548.4075	4.225493	9.52E+11	-2.3E+11	9.79E+11	Clothoid Curve (ETC)
1045	758.8485	549.3806	4.225634	-9.8E+11	2.31E+11	1E+12	Tangent Section - constant gradient

The comparison of coordinates from the algorithm and coordinates of highway CAD drawing are summarized in Table 2.

Table 2. Coordinates from the Algorithm and Coordinates from CAD Drawing

Section		Calculated Coordinates	CAD Coordinates
Beginning point of Clothoid Curve(BTC)	x	165.1767	165.6701
	y	19.44084	19.4989
Beginning Point of Simple Circular Curve (BC)	x	469.3157	469.6823
	y	90.75371	90.9323
End Point of Simple Circular Curve (EC)	x	652.3714	652.5209
	y	253.6001	253.8314
End Point of Clothoid Curve(ETC)	x	758.6182	758.4308
	y	548.4075	547.6157

The clothoid parameter A, radius of curve R, length of simple circular curve S, central angle Θ are shown in Table 3.

Table 3. Comparison of R, S, Θ, A

Design Elements	Calculated	CAD	Equation
Radius of Curve(R)	460m	460m	<Equation 5>
Central Angle(Θ)	30.6°	30°	<Equation 9>
Length of Simple Circular Curve(S)	246m	247.9m	<Equation 10>
Clothoid Parameter(A)	380m	380m	<Equation 13>

When Table 2 and 3 are compared, the calculated coordinates and values from the algorithm are not different with those of highway CAD drawing.

3.2 Reverse Horizontal Curve Case

In order to test the analysis algorithm, reverse curve case was analyzed which are shown in Figure 11. The highway alignments are composed of ‘tangent section-simple circular curve 1-simple circular curve 2- simple circular curve 3 – tangent section. The developed algorithm was applied.

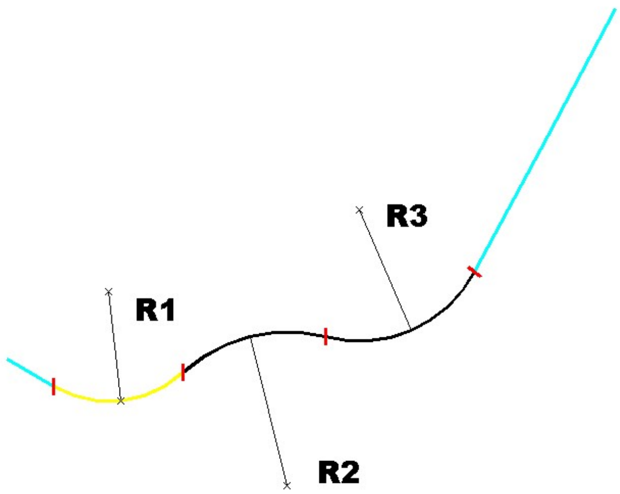


Figure 11. Reverse Curve Case

For the reverse curve case, the calculation of the center of curve (x_M, y_M) from the consecutive three points and radius R is shown in Figure 12. For the circled points, the center of curve and radius do not have constant values, and after the certain section, the center of curve and radius has constant values.

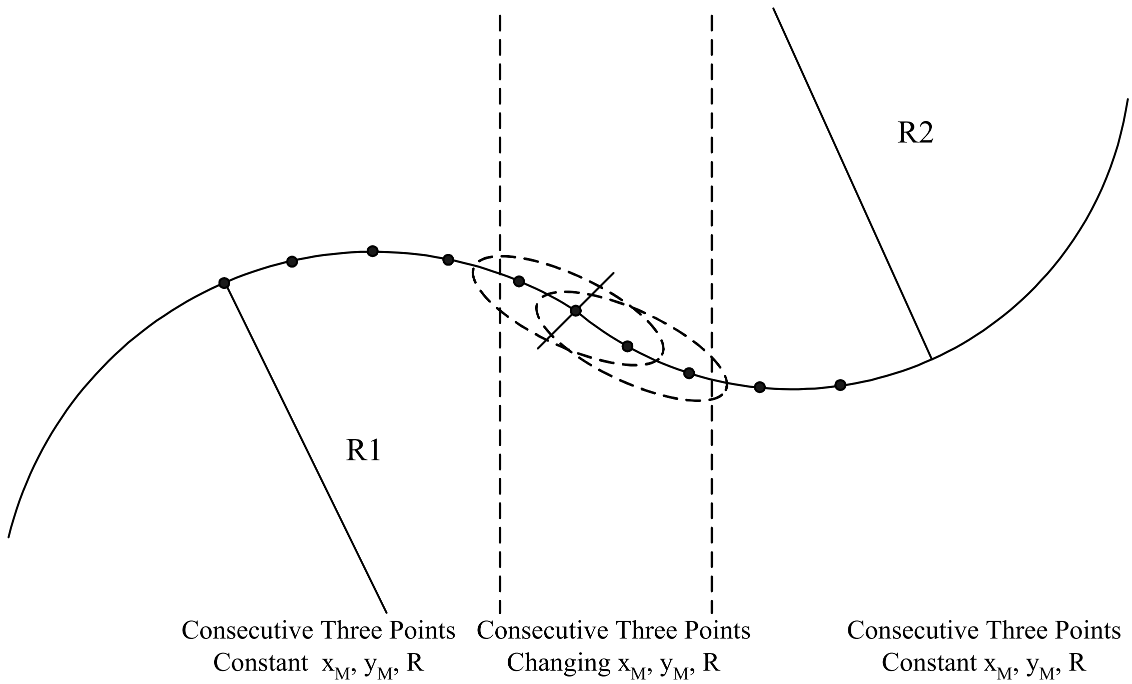


Figure 12. Change of Center of Curve and R for the Reverse Curves

For the reverse curve analysis, tangent section, simple circular curve 1, simple circular curve 2, and simple circular curve 3 were analyzed and summarized in Table 4. Table 4 shows that the gradient is changing at the point of curve, for the simple circular curve 1, the center of curve (x_M, y_M) and radius of curve R are constant for the simple circular curve 2 and 3. As shown in Figure 8, if gradient is changing and the center of curve (x_M, y_M) and the radius of curve R are changing for a relatively long section, the curve is assumed as transition curve. Then the analysis of transition curve is performed. However, if the gradient is changing and the center of curve (x_M, y_M) and the radius of curve R are changing only for short section, then it is assumed that this section is the part of the reverse curve.

Table 4. Coordinates and Horizontal Alignment Analysis for the Reverse Curve

No	x	y	gradient	x_M	y_M	R	section
1	473.79556	196.70587					
2	474.65870	196.20091	-0.585034				
3	475.52184	195.69594	-0.585034	-9.259E+11	-6.141E+02	9.26E+11	
4	476.38498	195.19098	-0.585034	1.759E+13	-1.583E+12	1.77E+13	
5	477.24812	194.68601	-0.585034	2.056E+13	3.007E+13	3.64E+13	Tangent Section
6	478.11126	194.18105	-0.585034	-1.292E+12	3.515E+13	3.52E+13	- constant gradient
7	478.97440	193.67608	-0.585034	1.495E+12	-2.208E+12	2.67E+12	
…… omitted……							
246	685.26473	72.98931	-0.585034	1.352E+12	6.028E+12	6.18E+12	
247	686.12787	72.48434	-0.585034	-1.100E+12	2.312E+12	2.56E+12	
248	686.99101	71.97938	-0.585034	-1.118E+13	-1.879E+12	1.13E+13	Circular Curve 1
249	687.85428	71.47463	-0.584696	2.693E+03	-1.910E+13	1.91E+13	
250	688.71843	70.97140	-0.582348	9.756E+02	3.501E+03	3442.385	
251	689.58358	70.46989	-0.579672	9.399E+02	5.645E+02	553.867	
252	690.44974	69.97012	-0.577004	9.399E+02	5.033E+02	500	Circular Curve 1
253	691.31689	69.47207	-0.574341	9.399E+02	5.033E+02	500	-changing gradient
254	692.18504	68.97577	-0.571684	9.399E+02	5.033E+02	500	- - constant x_M, y_M, R
…… omitted ……							
882	1276.18342	133.27576	0.906986	9.399E+02	5.033E+02	500	
883	1276.92279	133.94906	0.910638	9.399E+02	5.033E+02	500	
884	1277.66081	134.62384	0.914303	9.399E+02	5.033E+02	500	
885	1278.39748	135.30009	0.917982	9.399E+02	5.033E+02	500	Circular Curve 2
886	1279.13320	135.97738	0.920582	7.981E+02	5.033E+02	605.2192	
887	1279.86968	136.65383	0.918485	1.875E+03	6.577E+02	790.8847	
888	1280.60714	137.32923	0.915854	1.753E+03	-5.118E+02	802.8638	Circular Curve 2
889	1281.34555	138.00357	0.913231	1.753E+03	-3.792E+02	700	-changing gradient
890	1282.08493	138.67686	0.910614	1.753E+03	-3.792E+02	700	- - constant x_M, y_M, R
891	1282.82527	139.34909	0.908004	1.753E+03	-3.792E+02	700	
…… omitted ……							
1583	1927.60110	298.65440	-0.256782	1.753E+03	-3.792E+02	700	
1584	1928.56932	298.40430	-0.258305	1.753E+03	-3.792E+02	700	
1585	1929.53718	298.15282	-0.259830	1.753E+03	-3.792E+02	700	Circular Curve 3
1586	1930.50482	297.90048	-0.260786	1.648E+03	-3.792E+02	733.6482	
1587	1931.47281	297.64949	-0.259288	2.110E+03	-7.829E+02	1095.221	
1588	1932.44122	297.40011	-0.257510	2.082E+03	9.878E+02	706.3429	
1589	1933.41004	297.15235	-0.255734	2.082E+03	8.786E+02	600	Circular Curve 3
1590	1934.37927	296.90621	-0.253959	2.082E+03	8.786E+02	600	-changing gradient
1591	1935.34891	296.66168	-0.252185	2.082E+03	8.786E+02	600	- constant x_M, y_M, R
…… omitted ……							
2384	2609.46865	593.37529	1.847295	2.082E+03	8.786E+02	600	
2385	2609.94323	594.25550	1.854672	2.082E+03	8.786E+02	600	
2386	2610.41661	595.13636	1.860812	1.972E+03	8.786E+02	698.8542	Tangent Section
2387	2610.88986	596.01729	1.861446	-3.589E+03	9.379E+02	6209.69	
2388	2611.36311	596.89822	1.861446	-9.007E+15	3.926E+03	9.01E+15	
2389	2611.83636	597.77915	1.861446	-9.007E+15	4.839E+15	1.02E+16	Tangent Section
2390	2612.30961	598.66008	1.861446	2.200E+12	4.839E+15	4.84E+15	- constant gradient
2391	2612.78286	599.54100	1.861446	-1.939E+12	-1.182E+12	2.27E+12	

The comparison of coordinates from the algorithm and coordinates of CAD drawing are summarized in Table 5.

Table 5. Comparison of Coordinates for the Beginning Points of Curves

Section	Coordinates of Beginning Points			
	CAD		Calculated	
	x	y	x	y
Circular Curve 1	687.4211	71.7278	686.9910	71.9794
Circular Curve 2	1278.7013	135.5798	1278.3974	135.3001
Circular Curve 3	1929.9367	298.0468	1929.5372	298.1528
Tangent Section	2610.1388	594.6192	2610.4166	595.1364

The comparisons of radii of curves, lengths of curves, and central angles are shown in Table 6.

Table 6. The Comparison of R, S, ϴ for the reverse curve

Section	Radius of Curve(R)		Length of Curve(S)		Central Angle(ϴ)	
	CAD	Calculated	CAD	Calculated	CAD	Calculated
Curve 1	500	500	636.91	637.00	73.0	73.0
Curve 2	700	700	700.00	700.00	58.0	57.3
Curve 3	600	600	800.00	801.00	77.0	76.5

When Table 5 and 6 are compared, the horizontal alignment analysis algorithm is applicable for the simple curves and clothoid curves.

4. CONCLUSION

In this research, the horizontal alignment analysis algorithm was developed which can recognize the highway sections whether they are tangent sections or curve sections using the real world coordinate data. The proposed algorithm for horizontal curve analysis includes the identification of beginning and ending points of horizontal curves for the circular and transition curves, the parameter of clothoid, radius of circular curve, and length of circular and transition curves. The calculated coordinates for the beginning of curve, beginning of tangency, values for the radius, length of curve, clothoid parameter, and central angle show almost similar to the real world coordinates and real world values. The identification algorithm of horizontal curves expects to be used as a basis of automatic procedure which can identify the highway deficient sections along the highway route and analyze highway safety in terms of quantitative measures.

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