Journal of Soft Computing in Civil Engineering 2-2 (2018) 116-126

Contents lists available at SCCE

Journal of Soft Computing in Civil Engineering

Journal homepage: www.jsoftcivil.com

An Analysis of Sight Distances Considering Both the Vertical and Horizontal Curves of a Tourist Bound Destination Highway in Camarines Sur: The Lagonoy-Presentacion Section

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https://doi.org/10.22115/SCCE.2018.100391.1028

ARTICLE INFO

Article history:
Received: 08 October 2017
Revised: 22 February 2018
Accepted: 22 February 2018

Keywords:
Sight distance;
Vertical curve;
Horizontal curve;
Highway;
Maximum speed.

ABSTRACT

This analyzed sight distances contemplating both vertical and horizontal curves of a tourist bound destination highway in Camarines Sur, particularly the Lagonoy to Presentacion section. The Quantum Geographic Information System (QGIS) was used. The data were validated through site observation. The radius, tangent and sight distances for horizontal curves were obtained through graphical measurement while the elevations, length, slopes of both forward and back tangents, and sight distances of vertical curves were computed using mathematics formula. The decision sight distance and the equivalent maximum speed values were deduced through the policies imposed by the American Association of State Highway and Transportation Officials (AASHTO [1]). The highway has numerous horizontal and vertical curves with radius, tangent distances, intersecting angles, curve lengths; elevations of point of curvature (PC), point of tangencies (PT), and point of intersections (PI); and slope of forward and back tangent causal to short sight distances, delimiting car speeds. Through the obtained sight distance data, the maximum speed limit map was completed.

How to cite this article: Romero R.V. An analysis of sight distances considering both the vertical and horizontal curves of a tourist bound destination highway in camarines sur: the lagonoy-presentacion section. J Soft Comput Civ Eng 2018;2(2):116–126. https://doi.org/10.22115/scce.2018.100391.1028.

1. Introduction

The group of Caramoan island is increasingly attracting travelers making the province of Camarines Sur as one of the top tourist destinations. The passage is concreted that made it prevalent as the main route from the mainstream to the endpoint municipality. However, scrutiny in the design of the highway is necessary. Several factors must be deliberated in the highway design as driver's visibility is affected by the presence of dangerous curves. Highway designers always have to consider sight distance for it is vital in reducing road accident (Hassan and Easa [2]). The geometric design of a highway is a complex practice which is closely related to human insight and behavior (Hassan & Sayed [3]). Many sequencers had been structured to lessen road accident but other factors are causal like human behavior, vehicle, weather condition and road alignment (Abbas et al., [4]). In all design criteria, earthwork is included which is necessary to determine prime vertical alignment (Goktepe et al., [5]) and avoidance of the sudden change in vertical acceleration (Shebl [6]).

Characteristics of speed control and lane distribution on combination of vertical and horizontal curve vary according to lanes and combination of road alignment (Chen et. al., [7]) while if the limitations of horizontal stopping sight distance are valid, that if obstruction height is higher than the maximum, the highway engineers have to consider a trade-off by increasing the horizontal curve radius as well as adjusting the design (Bassan [8]). Geographic Information System (GIS) is among the applications that could determine unavailable data (Castro et al., [9]) while understanding the relationship between the driver speed behavior and the effectiveness of the warning signs position is necessary for reducing road fatalities (Discett [10]).

This study analyzed the sight distances, and highway bent from the municipality of Lagonoy to Presentacion in which highway curve data were focused on both vertical and horizontal curves. The more comprehensive analysis was conducted by computing the maximum speed limit. The final output is the maximum speed limit map.

2. Methodology

The Quantum Geographic Information System (QGIS) was used in analyzing the data which were validated through site observation. The radius, tangent and sight distances for horizontal curves were quantified through graphical measurement based on the satellite-fed data. Satellite-fed data are the data collected from QGIS through contour map reading. The intersecting angle was computed using equation 1:

$$R = \tan\frac{\theta}{2} \tag{1}$$

Where T is the tangent distance, R is the radius of the circular curve and Θ is the intersecting angle. The relationship between tangent distance, radius, and the intersecting angle is illustrated in Figure 1. Reflected also in the figure is the sight distance showing how it was measured.

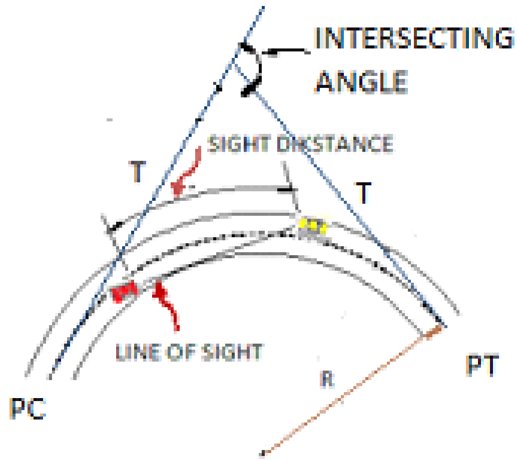

Fig. 1. Sight Distance in a horizontal curve of a circular highway.

For vertical curves, the elevations of Point of Curvature (P.C.), Point of Tangency (P.T.), and Point of Intersection (P.I.) were obtained through the contour lines provided by the QGIS map. Slopes of forward and back tangents were computed using slope formula while sight distance was computed utilizing the following formula: For summit parabolic curve, the following equations were applied to the following conditions:

When S < L

$$L = \frac{A}{100} \cdot \frac{S^2}{\left(\sqrt{2}h_1 + \sqrt{2}h_2\right)^2} \tag{2}$$

When S > L

$$L = 2S - \frac{200}{A}\left(\sqrt{h_1} + \sqrt{h_2}\right)^2 \tag{3}$$

$$A = g_1 + g_2 \tag{4}$$

For Sag Parabolic Curve the following equations were applied:

When S < L

$$L = A\frac{S^2}{(122 + 3.5S)} \tag{5}$$

When S > L

$$L = 2S - \frac{(122 + 3.5S)}{A} \tag{6}$$

Where:

$$A = g_2 - g_1 \quad (7)$$

L = length of the curve

S = sight distance

h_1 = height of the driver's eye

h_2 = height of the object

g_1 = slope of the back tangent

g_2 = slope of the forward tangent

The vehicles used were assumed a car with a height of 1.07 m. while the object is another car with a height of 1.07 m. The equivalent maximum design speed limit was done using the recommended decision sight distance values on avoidance maneuver for speed, path and direction change for the rural road. Decision sight distance is the distance needed for a driver to detect an unexpected or otherwise difficult to perceive information sources or condition in a roadway that may be visually cluttered, recognize the condition or its potential threat, select an appropriate speed and path, and initiate and complete the maneuver safely and efficiently. Figure 2 shows the vehicle sight distance on a vertical parabolic curve.

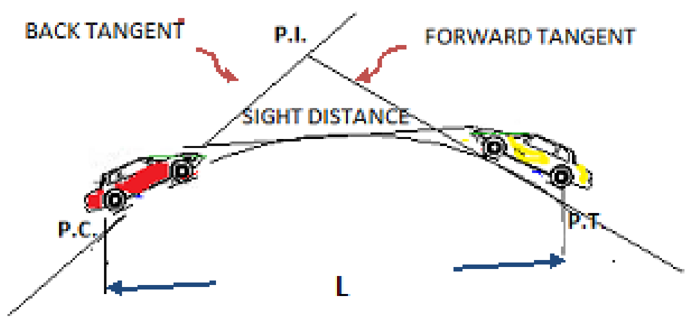

Fig. 2. Sight Distance on Vertical Curve.

The t-test was the statistical tool used to prove the following hypotheses: 1) Is there a significant difference on the radius and distance of the horizontal circular curve? 2) Is there a significant difference in the slope of back and forward tangents? and 3) Is there a significant difference in the sight distance due to the effect of the horizontal and vertical curves? The data were treated at 0.05 level of significance.

3. Results and discussion

3.1. The highway

The total highway distance is 29,044.0 m. with three hundred eighty-eight (388) identified curves. Two hundred ninety-six (296) are horizontal circular curves (76.29%) of different radius, tangent distances, and intersecting angles while ninety-two (92) are vertical parabolic curves (23.71%) of varying length, slopes of forward and back tangent; and elevations of Points of Tangency (P.T.), Points of Intersection and Points of Curvature (P.C.). Their locations could address a sight distance limitation which is needed for highway design guidance and in providing appropriate warning devices and speed limits that could minimize crash frequency, as it was proven that the drivers selected the apparent safe speeds according to the most preventive geometric feature (Al-Kaisy et al., [11]).

3.2. Elements of the horizontal curves

The length of their tangent distances reaches up to the range of 201-250 meters wherein majority (93.23%) is ranging from 1-50 meters with a mean length of 30.23 meters. The radius (0.68%) ranges up to the length of 351-400 meters but mostly (45.27%) are ranging from 1-50 meters. It has a mean length of 76.01 meters (See Table 1).

Table 1
Length of Tangent Distance and Radius of the Horizontal Curves

Tangent Distance			Radius	
Length	Frequency	%	Frequency	%
351-400	0	0	2	0.68
301-350	0	0	1	0.34
251-300	0	0	4	1.35
201 – 250	1	0.34	5	1.69
151 – 200	0	0	21	7.09
101 – 150	2	0.67	47	15.88
51 – 100	20	6.76	82	27.70
1-50	273	92.23	134	45.27
Total	296	100	296	100
Mean = 30.26 m.			Mean = 76.84	

Note: Computed t = 3.06 > critical value = 1.60

The outcome of short tangent distance and radius is a short sight distance (Fink and Krammes [12]) but it was suggested that the safety effects of long approach tangent length and short approach sight distance become more pronounced on piercing curves as sight distance would adversely be affected especially when the horizontal curve is sharp (Ali et. al., [13]). Sight distance is always related to the circular arcs, the length of the tangent, the locations of the driver and object, and the location of the vision-limiting obstacle (Easa [14]).

The intersecting angle (0.34%) reaches 61º-70º; however, the majority (42.23%) is within the range of 11º-20º. The mean intersecting angle is 22.18º (See Table 2).

Table 2
The Intersecting Angle.

Intersecting Angle	Frequency	%
61º - 70 º	1	0.34
51 º - 60 º	3	1.01
41 º -50 º	18	6.08
31 º - 40 º	58	19.59
21 º - 30 º	85	28.72
11 º - 20 º	125	42.23
1º - 10º	6	2.03
Total	296	100
Mean = 22.18º		

The number of accidents increases exponentially with the degree of the curve (Matsoukis [15]). However there are remedies that can be done in order to maintain less constraint and provide more comfort driving, that is if the horizontal curve is designed to a smaller superelevation rate. In simple circle curves, the accident rate per kilometer is increased by increasing the inner intersection angle which was explained by the driver's mistake in distinguishing the arc curvature (Kamali et al., [16]).

3.3. Elements of the vertical curves

There are ninety-two (92) vertical curves in which their length (2.17%) reaches up to the range of 601-700 meters however majority (35.87%) has a length in the range of 101-200 meters. The mean length of the vertical parabolic curves is 209.20 meters (See Table 3).

Table 3
Length of the Vertical Curve.

Length	Frequency	%
601-700	2	2.17
501-600	3	3.26
401-500	6	6.52
301-400	8	8.70
201-300	19	20.65
101-200	33	35.87
1-100	21	22.83
Total	92	100
Mean = 209.20		

Transitioned vertical curve improves sight distance which is opposite the spiraled horizontal curves which worsen when modified (Easa & Hassan [17]). Poor sight distance in horizontal curves is the result of the higher accident rate (Zhang [18]).

The highest elevation for Point of Intersection (P.I.) ranges from 51-60 meters (1.09%) while for the Point of Curvature (P.C.) (2.17%) and Point of Tangency (P.T.) (3.26%) ranges from 41-50 meters. The mean elevation for the P.C., P.I., and P.T. are 23.22 m., 18.66 m. and 23.21 m.

Table 4
Elevation of the Points of Curvature, Intersection, and Tangency.

Elevation	Point of Curvature (PC)		Point of Intersection (PI)		Point of Tangency (PT)	
(m)	F	%	F	%	F	%
51-60			1	1.09		
41-50	2	2.17	7	7.61	3	3.26
31-40	11	11.96	24	26.09	9	9.78
21-30	46	50.00	36	39.13	46	50.00
11-20	30	32.61	21	22.82	32	34.78
1-10	3	3.26	3	3.26	2	2.18
Total	92	100	92	100	92	100
Mean	23.22 m.		18.66 m.		23.21 m.	

Elevations of PC, PI and PT indicate that the highway is in a mountainous area which will involve large amount of earthwork quantity utilization; however, there are steps to follow to minimize the overall cut and fill quantities before the grades are connected together with a parabolic curve (Dabbour [19]).

The highest slope for back tangent (1.09%) ranges from 30.1% - 35.0% which is similar to the forward tangent (1.09%). However, the majority (32.62%) of the back tangent has a slope of 0.10% to 5.0% while its mean slope is 8.85%. Majority of the forward tangent (41.30%) has a slope of 0.10% - 5.0% while the mean slope 8.57%.

Table 5
The slope of Back and Forward Tangents.

Slope (%)	Back Tangent		Forward Tangent	
	Frequency	%	Frequency	%
30.1-35	1	1.09	1	1.09
25.1-30	0	0	0	0
20.1-25	5	5.43	6	6.52
15.1-20	10	10.86	8	8.70
10.1-15	24	26.09	18	19.56
5.1-10	22	23.91	21	22.83
0.1-5	30	32.62	38	41.30
Total	92	100	92	100
Mean	9.47%		9.54%	

Note: Computed t = 0.479 < critical value = 1.653

Higher slopes of forward and back tangent are the cause of distress of the riders while well-designed curves result rider's comfort in the highway due to its smoothness particularly at the beginning by which the rate of change in slopes equals zero. The gradual change of the rates in grade provides more comfort to the driver (Sun & Chen [20]).

3.4. Sight distance

Sight distances (97.30%) in the horizontal curves are ranging from 1-145 meters which has an equivalent maximum speed of 50 kilometers per hour (km/h) based from the recommended decision sight distance for rural areas by AASTHO. Other horizontal curves (2.70%) have sight distance ranging from 146-170 meters with an equivalent maximum speed of 60 km/h. (See Table 6)

Table 6
Equivalent Maximum Speed Value of Decision Sight Distance.

Vertical Curve				Horizontal Curve		
Sight Distance	Equivalent maximum Speed(K/h)	Frequency	%	Equivalent maximum Speed	Frequency	%
361-390	130	6	6.52	0	0	0
331-360	120	0	0	0	0	0
316-330	110	0	0	0	0	0
271-315	100	2	2.17	0	0	0
231-270	90	2	2.17	0	0	0
201-230	80	1	1.09	0	0	0
171-200	70	4	4.35	0	0	0
146-170	60	11	11.96	60	8	2.70
1-145	50	66	71.74	50	288	97.30
Total		92	100	Total	296	100

Note: Computed t = 7.462 > critical value = 1.967
Null Hypothesis was accepted

Major parts of the highway are appropriate for low speed as speed reduction is considered one of the major factors in contributing road safety (Ona et al. [21]). For this reason, several guidelines have to be recommended for maximum desirable speed reductions (Luque & Castro [22]). A need for highway design guidance could give higher priority to address sight distance limitations (Harwood & Bauer [23]).

3.5. Maximum speed limit

The maximum speed limit for horizontal curves shows that majority (70.12%) are designed for a speed of 50 KPH which comprises a total distance of 20,365.65 M. It is similar to vertical curves comprising a total distance (41.58%) of 12,076.49 M. This is also the same in combining both horizontal and vertical curves at total distance (67.76%) of 19,680.21 M.

Table 7
Distance Covered by Maximum Speed Limit.

Horizontal Curve			Vertical Curve		Horizontal and Vertical Curve	
Maximum Speed Limit (KPH)	Length (M)	%	Length (M)	%	Length (M)	%
130	3,485.28	12.00	6302.55	21.70	816.13	2.81
120	0	0	1890.76	6.51	1,277.94	4.4
100	142.32	0.49	0	0	441.47	1.52
90	63.90	0.22	1661.32	5.72	897.46	3.09
80	1,054.30	3.63	1129.81	3.89	2335.14	8.04
70	1,966.28	6.77	1966.28	6.77	1,405.73	4.84
60	1,966.28	6.77	4016.78	13.83	2,189.92	7.54
50	20,365.65	70.12	12,076.49	41.58	19,680.21	67.76
Total	29,044.00	100	29,044.00	100	29,044.00	

3.6. The maximum speed limit map

Table 7 was used to produce speed limit map. Making of the map was made by comprehending the horizontal and vertical curve data. Figure 3 is the final output which is reflecting that major portion of the map is suited for a maximum speed of 50 KPH (colored in red). This implies that it is the safest speed to be applied by the driver while passing in major parts of the highway. It is where the drivers can provide an appropriate division of maneuvering a car in highway curves.

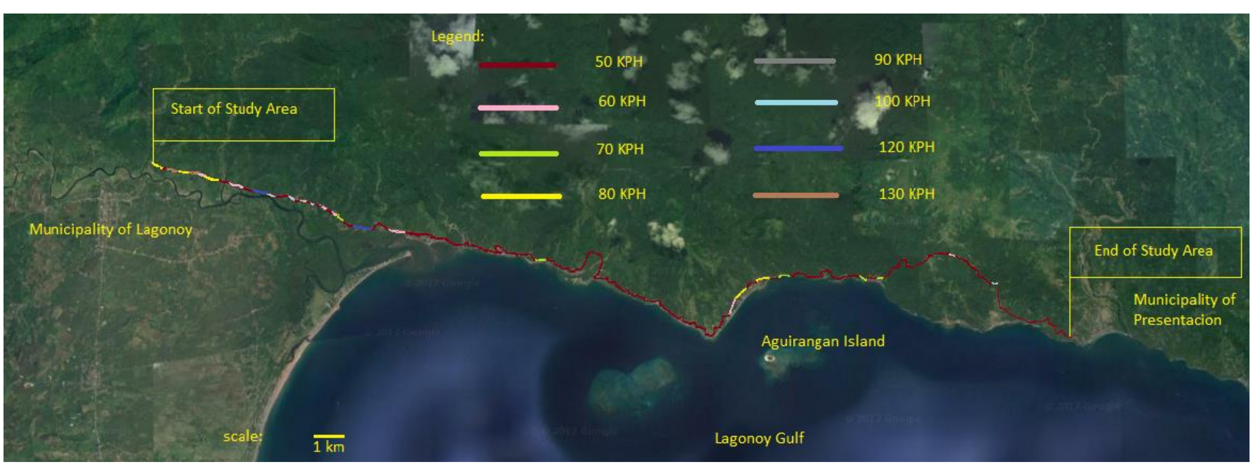

Fig. 3. The Maximum Speed Limit Map

4. Conclusion

Using of quantum geographic information system (QGIS) software application was found useful in producing speed limit map and in looking for the appropriate speed limits in the highway. The state of the vertical and horizontal curves that both contributes to the inadequacy of sight distances was detected and found as one of the causes of restricting car speed. Redesigning by means of eliminating highway curves is necessary in order to increase the length of sight distances and to insure travel safety. Although this study was completely successful in sensing the inadequacy of sight distances in major parts of the highway, but still there is a need to look for the other possibilities to be done. Among them is by analyzing if it is appropriate to apply the following: by widening the highway or by eliminating unnecessary curves and that is either by building bridges or tunnels. This steps could be a continuation of this study. The produced speed limit map may be used in information dissemination, as well as in locating traffic signs and early warning devices.

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