RELATIONSHIP BETWEEN SIGHT DISTANCE AND OPERATING SPEED ON HORIZONTAL CURVES

Piras C.
PhD Student – University of Cagliari – cpiras@unica.it
Pinna F.
Researcher – University of Cagliari – fpinna@unica.it

ABSTRACT

All guidelines give more or less interesting and considerations about stopping and passing sight distances. Sight distance is the portion of the roadway available for view at any given time. In the Italian design guidelines sight distance is considered an important factor for road safety. It is the base for the calculation of design elements such as curve radii and vertical curvatures. The amount of available sight distance is considered of the utmost importance in the safe and efficient operation of vehicles on a highway.

The aim of the analysis is to investigate the relationship between the operating speed and the geometric features, into the studies of several countries, in order to create an operating speed model, where the V_{85} is expressed as a function of Curvature Change Rate of the single curve (CCRs) and available sight distance.

In the beginning of the article, the most important national and international models, which enable to calculate V_{85} in the Italian highways, are summed up.

Then speed surveys, varying the available sight distance, are carried out. Driving speed in the midpoint curves is evaluated. During surveys just passenger vehicles in free flow are included (headway of at least 5 seconds). Besides different constraints have been imposed to select curve sites: rural area, marked and paved roadways with constant lane width, no intersections near to curve, longitudinal grades ≤ 6%.

The research project, which is carried out by the Department of Land Engineering of the University of Cagliari, aims to develop an analytical model that permits to calculate V_{85} as a function of CCRs and available sight distance.

Keywords: two-lane rural highway, speed prediction, operating speed, safety, sight distance

1. INTRODUCTION

Driver filters and processes informations, especially the visual ones, connected to the road environment. This perception changes accordingly to his psycho-physic conditions. In order to tackle these issues, several experimental studies carried out. These studies give more importance to the interaction between the driver and the external context, focusing the interest on the driver behavior.

Numerous researchers have carried out studies on the driver behavior, emphasizing the importance of defining analytical models that link driver behavior and road characteristics. From the studies examined emerges that the main relationships are those related to the real driving speed. In this regard the most important definition of speed that represents driver behaviour is operating speed (V_{85}). It is the speed value not exceeded by the 15 percent of the drivers [1]. The form of the operating speed prediction models and number of variables used in each of them vary considerably. The most common operating speed models, proposed by many researchers of different countries, provide V_{85} as a function of the Degree of Curvature (DC), the Curvature Change Rate of the single curve (CCRs) or the horizontal radius (R).

Moreover the majority of operating speed studies focuses on curved road sections, where high dangerous situations happen. On curve sections, one of the key criteria governing safety is the ability of a driver to recognise an hazard ahead and to take appropriate action to maintain control of the vehicle or avoid the hazard [2]. In this context sight distance has an important role.

Sight distance is the length of roadway available to a driver for view at a given time. It is an important key road safety factor too. The sight distance depends on driver reaction time, vehicle performances, roadway conditions, and so on. In the Italian road standards there are three types of sight distance:

- stopping sight distance;
- overtaking sight distance;
- changing lane sight distance.

This paper aims to analyse the relationships between operating speed and available sight distance on horizontal curves. In accordance with this target speed surveys are carried out on several curves with different available sight distances. Driving speed in the curve midpoint is evaluated. Thus the results of surveys are compared with several analytical models, which enable to calculate V_{85} in the Italian highways.

The research project, which is carried out by the Department of Land Engineering of the University of Cagliari, aims to develop an analytical model that permits to calculate V_{85} as a function of CCRs and available sight distance.

2. SIGHT DISTANCE ON HORIZONTAL CURVES

The analysis of sight distance is based on the premise that a driver should be given the opportunity to identify a problem, react and avoid the hazard [2]. In general the minimum sight distance available on a two lane rural roads is the stopping sight distance. It is the distance which at every point along the rural roads should be at least that required for a vehicle to stop.

Within Italian design the minimum stopping sight distance is calculated using the equation 1, that is a made example of the original form:

$$D = \frac{v^2}{2a} \qquad \text{(Eq. 1)}$$

(where: D = stopping sight distance [m], v = initial vehicle speed [m/s], a = deceleration [2÷2,5 m/s^2]).

This equation is suitable for calculating the braking distance of passenger vehicles.

In current geometric design practice, the design of horizontal curves involves the design engineer selecting the horizontal radius based on a minimum radius and maximum superelevation for a given design speed. Passenger vehicles may skid or rollover on horizontal curves. Equation 2 defines the minimum radius for a passenger vehicle for a given speed in most design guidelines [3].

$$R = \frac{V^2}{127(e_{max} + f_{max})} \qquad \text{(Eq. 2)}$$

(where: V = design speed [km/h], e_{max} = maximum allowable superelevation [m/m], f_{max} = maximum allowable lateral coefficient of friction)

When a vehicle is braking on a tangent section of road, it is assumed that the entire frictional force is available to be used for braking. On a horizontal curve, some of the frictional force is used to supply the lateral force required for centrifugal acceleration. Therefore, a reduced amount of frictional force is available for braking [3].

Different analytical models have been used to calculate the minimum distance that an object can be offset from the centreline of the inside travel lane without restricting the required sight distance [3]. Figure 1 shows, in plan, how an object can restrict horizontal sight distance. The distance M can be calculated with following equation [3]:

$$M = R\left[1 - \cos\left(\frac{28.65 \times SD}{R}\right)\right] \qquad \text{(Eq. 3)}$$

(where: M = middle ordinate [m], R = radius of the horizontal curve [m], SD = required sight distance [m], L = length of curve [m].

Equation 3, valid when the alignment contains a simple horizontal curve and the length of circular curve is greater than the sight distance, links distance between an object can restrict horizontal sight distance and external margin to required sight distance and horizontal curve radius [3].

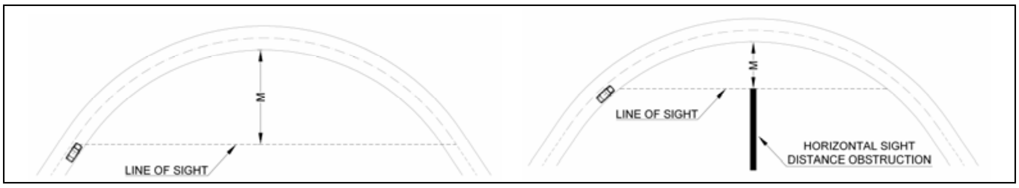

Figure 1 Available sight distance without and with restriction

Figure 2 shows the maximum central offset required with varying horizontal curvature, in order to maintain the design speed related to stop sight distances [4].

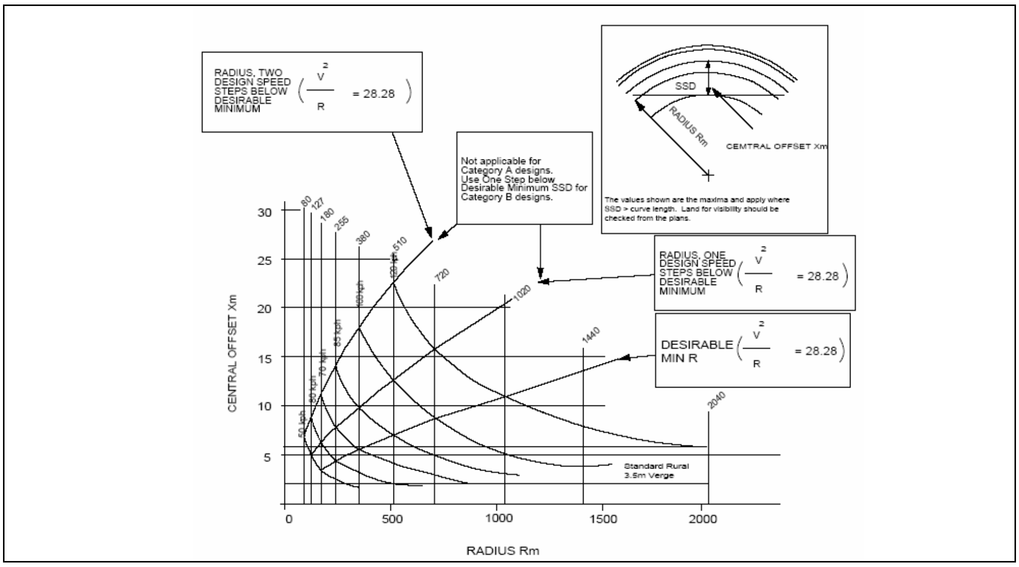

Figure 2 Verge widening for desirable minimum stopping sight sistance [4]

Figure 3 shows the maximum central offset required with varying horizontal curvature, in order to maintain the design speed related Full Overtaking Sight Distance's [4].

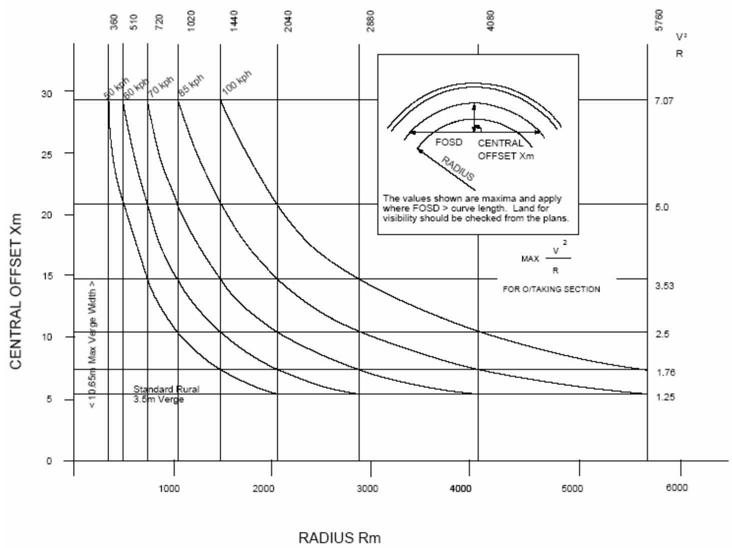

Figure 3 Verge Widening for Full Overtaking Sight Distance [4]

It is most interesting to verify how available sight distance influences operating speed. On one hand several studies define that relationships between these values are unimportant; on the other hand in some country the relationship between sight distance and operating speed is used to verify design consistency of highways.

3. CASE STUDY

In the first of our research project, we have analysed how operating speed changed with different available sight distances. Four curve sections, with different available sight distances in the start point of curve, in Cagliari province have been chosen. The horizontal radii investigated ranged from 50 m to 100 m. The surveys were carried out during daylight hours, in good weather conditions and with a dry pavement. The data collecting excludes non-passenger cars and vehicles with less than 5 second headway from the previous vehicle (free flow).

The road alignments are made up of tangent and circular curves, there are not clothoids. In fact, the highways, that are considered in this analysis, have been designed with preceding guidelines within them clothoids were not mentioned. The speed data are collected at middle point of the horizontal curve.

The first scenarios (sites n. 1 and n. 2) assumed that in the start point of curve section the available sight distance is at least equal to length of curve. Instead the second scenarios (sites n. 3 and n. 4) supposed that the available sight distance is minor than length of curve.

3.1 Site n. 1 – S.S. n. 547

The curve section is located along the S.S. n. 547. The cross-section is made up of two lanes that are 3,50 m wide, no paved shoulders which are 1,00 m wide and longitudinal grade is 3,75 %.

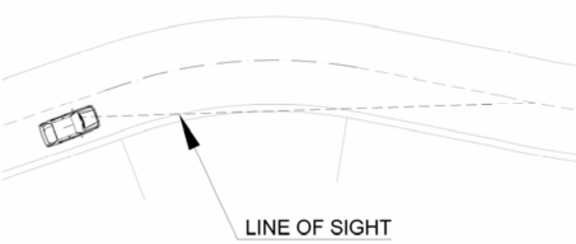

Figure 4 Plan of horizontal curve – Site n. 1

We were carried out the measurement in a road section preceding by a tangent and succeeding by a curve. The horizontal curve radius is 70 m. A total of 128 individual speed observations are collected on one direction. The operating speed registered is 60 km/h.

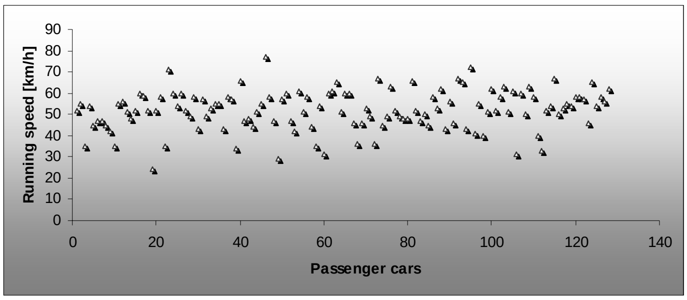

Figure 5 Speed values gathered on site n. 1 (S.S. n. 547)

Figure 6 Site n. 1 (S.S. n. 547)

3.2 Site n. 2 – S.S. n. 125 (km 52)

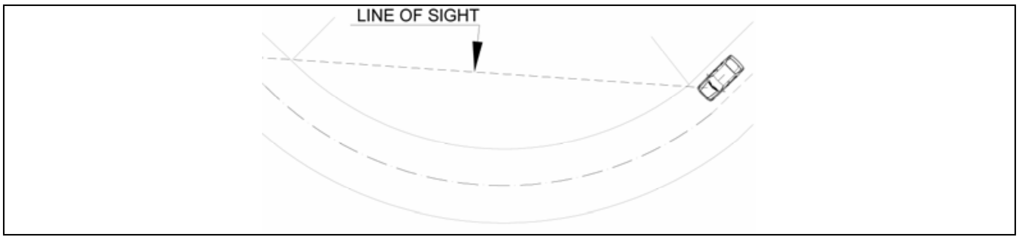

Figure 7 Plan of horizontal curve – Site n. 2

The curve section is located along the S.S. n. 125. The cross-section is made up of two lanes which are 3,25 m wide, no paved shoulder that are 0,50 m wide. The longitudinal grade is 2,70 %. The horizontal curve radius is 55 m. A total of 168 individual speed observations are collected on both directions. The operating speed registered is 49 km/h.

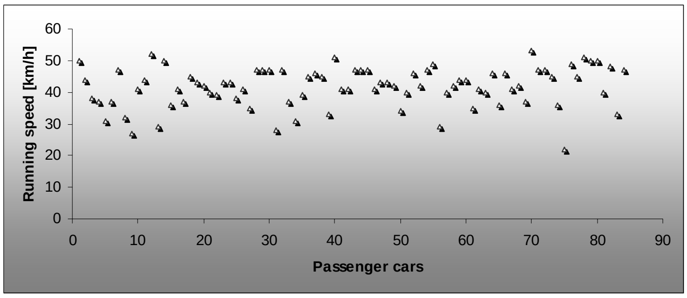

Figure 8 Speed values gathered on site n. 2 (S.S. n. 125 - km 52)

3.3 Site n. 3 – S.P. n. 20

The curve section is located along the S.P. n. 20. The cross-section is made up of two lanes that are 3,25 m wide, no paved shoulders that are 0,50 m wide. Longitudinal grade is 3,75 %. We were carried out the measurement in a road section preceding and succeeding by other circular curves.

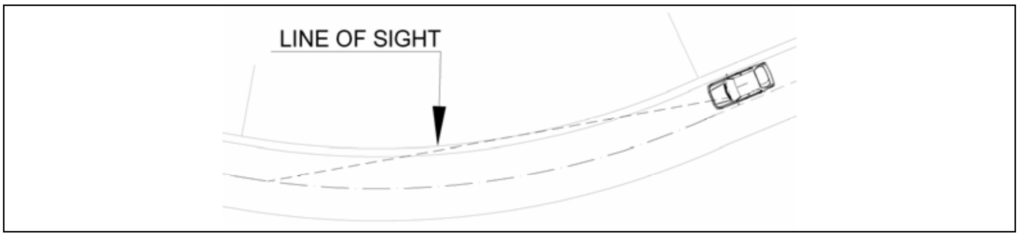

Figure 9 Plan of horizontal curve – Site n. 3

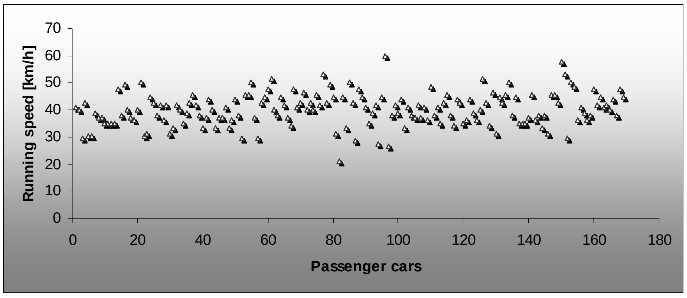

Figure 10 Speed values gathered on site n. 3 (S.P. n. 20)

The horizontal curve radius is 100 m. A total of 168 individual speed observations are collected on one direction. The operating speed registered is 45 km/h

3.4 Site n. 4 – S.S. n. 125 (km 25,2)

The curve section is located along the S.S. n. 125. The cross-section is made up of two lanes that are 3,25 m wide, no paved shoulders that are 0,50 m wide. Longitudinal grade is 4,00 %.

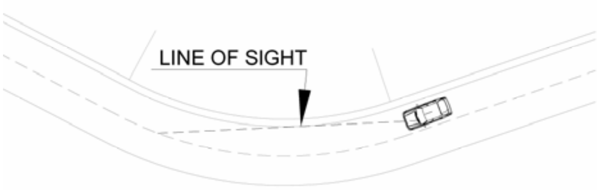

Figure 11 Plan of horizontal curve - Site n. 4

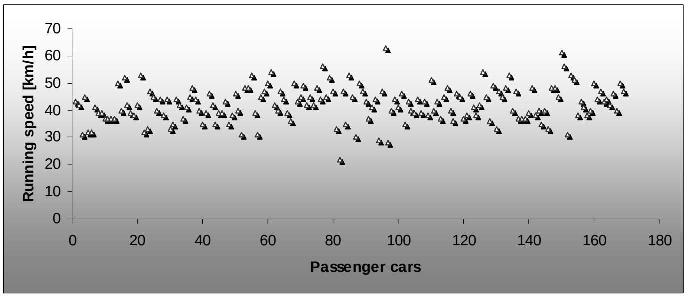

Figure 12 Speed values gathered on site n. 4 (S.S. n. 125 - km 25,2)

The horizontal curve radius is R = 50 m. A total of 169 individual speed observations are collected on both directions. The operating speed registered is 48 km/h. In this case the available sight distance is minor than total horizontal curve length.

Table 1 summarized the main values of speed distribution and features of several horizontal curves.

Table 1 Horizontal curve features

	Site n. 1 S.S. 547	**Site n. 2** S.S. 125	**Site n. 3** S.P. 20	**Site n. 4** S.S. 125
Horizontal Curve Radius R [m]	70	55	100	50
Length of Horizontal Curve [m]	35	80	60	40
Available Sight Distance [m]	60	90	55	35
Longitudinal grade [%]	3,75	2,70	3,75	4,00
Total observations	128	168	168	169
V_{85} [km/h]	60	49	45	48

The most common operating speed models for two-lane rural highways express V_{85} as a function of horizontal curvature even if other curve elements were found to be significant.

Each model has been created on the basis of local road environment conditions: lane and shoulder width, longitudinal grade, range of horizontal curve radius, dry or wet pavement, and so on. In this paper the models that are based on road features similar to Italian road characteristics are only considered, in all. Several models have been chosen and applied on four sites.

Subsequently the models whose results are a lot different than data collected have been excluded.

Table 2 sums up the prediction models that at the end have been used in our study. In the table, for each site, operating speed values, calculated using speed prediction models, are inserted.

Besides in the second line the V_{85}, gathered during surveys, are added in order to allow to do an immediately comparison between several values.

On the first two sites operating speed values collected are similar to ones calculated with selected analytical models.

On the site n. 3 the operating speed surveyed is minor than model results. In this case the available sight distance is minor than total horizontal curve length, so it is possible that operating speed could be influenced by available sight distance.

Besides, on the site n. 4 available sight distance appears no affecting operating speed values.

Table 2 Operating speed calculated using speed prediction models

Model	**Equation**	**Site n. 1**	**Site n. 2**	**Site n. 3**	**Site n. 4**
		V_{85} (surveyed) 60	**V_{85}** (surveyed) 49	**V_{85}** (surveyed) 45	**V_{85}** (surveyed) 48
McLean Australia [5]	V_{85} = 101.2 – 0.043 CCRs	62	51	73	46
Lamm et al. Germany [5]	$V_{85} = 10^6$ / (8270 + 8.01 CCRs)	64	60	75	54
Psarianos et al. [5]	$V_{85} = 10^6$ / (10150.1 + 8.529 CCRs)	56	50	64	48
Krammes and Ottesen [5]	V_{85} = 103.04 – 0.053 CCRs	55	42	69	35
Ottesen and Krammes [6]	V_{85} = 103.66 – 1.95 · (1746.38 / R)	55	42	70	36
Kannelaidis et al. [7]	V_{85} = 129.88 – (623.1 / $\sqrt{R}$)	55	46	68	42
where: V_{85} [km/h]; CCRs [gon/km]; R [m].					

Other surveys and analysis are necessary, because of high heterogeneity of results summarized in table 2, in order to verify the real relationship between available sight distance on start point of horizontal curve and operating speed on middle point.

4. CONCLUSION

Operating speeds on roadways are highly variable. Drivers will select their desired operating speed for that element and will change their desired speed from element to element.

In this paper only operating speed models, which have been built on the basis of speed surveys on two lane rural roads, have been considered.

As shown by the cases studied, restricted sight distance caused by horizontal sight distance obstructions leads to drivers reducing running speed only in one road-site.

The next steps of the research work are:

- collecting data on other sites and studies the results;
- choosing a few horizontal curves with high available sight distance and gathering running speed on three sections (start point, middle point and end point);

- reducing available sight distance gradually and collecting travelling speed on the three sections;
- calculating operating speed value and verifying relationships between V_{85} and available sight distance.

The aim of the analysis is to investigate the relationship between the operating speed and the geometric features, into the studies of several countries, in order to create a operating speed model, where the V_{85} is expressed as a function of Curvature Change Rate of the single curve (CCRs) and available sight distance.

This paper represents a first step of our research project. In fact, the data surveys have been collected all the year round 2006. The following step will be select other sites to know the model that represents better the driver behavior on rural roads, which are designed in accordance with the new Italian Road Guidelines.

ENDNOTES

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