

CETRA²⁰¹⁴

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

Stjepan Lakušić – EDITOR

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation



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RELATION BETWEEN SPEED INCONSISTENCY AND DRIVING SAFETY ON CROATIAN STATE ROAD D-1

Biljana Vukoje, Dražen Cvitanić, Ante Proso

University of Split, Faculty of Civil Engineering, Architecture and Geodesy, Croatia

Abstract

Traffic accidents and road fatalities present a serious problem of the modern age. Statistics show that large percentage of traffic accidents with fatalities occur on horizontal curves which indicates that, in addition to drivers' errors, causes of road accidents can be found in the characteristics of the road alignment. Driving safety depends on several factors and one of the main causes of accident occurrence is the lack of geometric design consistency in terms of maintaining the desired travel speed. Design consistency refers to the ability of geometric characteristics of the road to conform to driver expectancy. A consistent road design ensures coordinated successive elements producing harmonized driver behaviour with no surprising events. Beside the successive elements consistency, a good road design must establish the balance of superelevation and side friction values in curves with actual driving speeds. Although numerous speed studies have been conducted, most of them were based on spot speeds and certain assumptions providing incomplete information about the actual speeds. The limitations of the existing studies indicate the need for more detailed research of actual driver behaviour and the inclusion of real speeds in the road design procedure. This paper presents the free flow speed analysis, with speeds recorded on a segment of the state road D1 in Dalmatia region of Croatia using an innovative GPS based methodology. This methodology allows the continuous speed data collection and gives an accurate picture of drivers' behaviour. The data were collected on 27 km long road segment and used for three types of analysis: relationship between project speeds and actual speeds of most drivers, comparison between side friction factors (demand, supply and design) and creation of the operating speed model in horizontal curves.

Keywords: GPS, operating speed, project speed, horizontal curve, side friction factor, operating speed model

1 Introduction

Factors mainly affecting road safety are: the driver, the vehicle and the road [1]. Previous road safety studies showed that accidents often occur on horizontal curves which indicates that there is a relationship between the traffic safety and road alignment characteristics. Previous accident researches have found that accident rates on horizontal curves are 2 to 5 times higher than the accident rates on tangents [2, 3]. Also in Croatia a large percentage of fatalities are related to horizontal curves. According to [4], approximately 40% of total fatalities that occurred in crashes in 2011 in Croatia occurred along horizontal curves.

2 Road design practice

All current geometric design policies are based on the design speed concept. A road design procedure begins with selecting a speed called “design speed” which is used for determination of the various geometric design features of the roadway. Among other elements, the most important one is determination of the allowable horizontal curve radii. The use of design speed enables driving safety in those sharpest curves, while road segments with flatter curves allow for higher driving speeds [5]. Some road design guidelines, like German [6] and Australian [7], recognize this by using the 85th percentile operating speed obtained by field survey. The operating speed is defined as the speed below which 85% of vehicles actually drive under free flow conditions.

Croatian guidelines for the road design [8] use theoretical value of speed, called project speed (V_p), rather than the 85th percentile operating speed. Project speed is defined as the maximum expected speed in free flow conditions that can be achieved with sufficient safety on a particular part of the road segment depending on its horizontal and vertical characteristics. It is determined from the basic equation of vehicle stability in horizontal curves, as a function of applied curve radius or largest applied longitudinal grade (smaller value is chosen):

$$V_p = \sqrt{127 \cdot R \cdot (e_{\max} + f_{R\text{design}})} \quad (1)$$

where:

V_p	project speed (km/h);
R	curve radius (m);
e_{\max}	maximum permissible superelevation;
$f_{R\text{design}}$	design side friction factor.

Croatian guidelines define the project speed as a criterion for determining superelevation and stopping sight distance. They also provide consistency criteria in terms of design and project speed consistency and consistency of project speeds within one road section. The values of project speeds should not exceed the design speeds by more than 20 km/h, otherwise the guidelines require that either the project speed be increased or the road alignment be modified to reduce the project speed. Also, the maximum differences in project speeds within one section should be less than 15 km/h.

Driving speeds are influenced by geometric elements such as horizontal curvature, cross-sections and grade, so it should be possible to control speed throughout the appropriate selection of geometric design standards for these elements [9]. Designing the geometric elements based on speeds not harmonized with actual speeds can result in inappropriate road elements. In particular, inadequate speeds in the road design process could result in superelevation and sight distance values that are less than optimal for safe and comfortable ride.

3 Data collection

Although numerous studies have been developed in order to determine operating speeds at curves, most of them were based on spot speeds and certain assumptions about drivers' behaviour. The lowest speeds along the horizontal curves and highest speeds along tangents are considered to be the desired drivers' speeds. The researchers collected speed data at specific locations of a roadway, mostly at the middle point of horizontal curves, using radar gun or similar device. Due to the lack of data, many models used the assumption of a constant velocity along a horizontal curve and the assumption that the acceleration and deceleration occur only on tangents. These assumptions may not be realistic [10, 11]. Except the unrealistic assumptions of driver behaviour, there are also some other disadvantages of spot speed

data measuring, like cosine error, drivers changing their behaviour in the presence of test equipment and human error when reading data from the device display. Because of the many shortcomings of the spot speeds and with the development of technology, more and more authors focus on continuous data measuring. In the past decade, several operating speed studies have been conducted based on continuous measured data using a GPS device [1, 10, 12, 13]. This paper presents the operating speed prediction model for horizontal curves based on the speed data from 10 km long road segment. The data were collected by using an innovative GPS device Performance Box, a high performance 10HZ GPS engine, which measures speed, position, acceleration and heading ten times a second. Performance Box uses a GPS system with an update rate of 10 samples per second, which is faster GPS engine than the devices of the previous reserches which were working with frequency of 1HZ. The GPS data collection methodology allows the determination of individual minimum speeds on curves and maximum speeds on tangents (location and value), unlike the spot speed models that used unrealistic assumptions of driver behaviour. Beside the speeds, GPS technology enables the determination of drivers' path radii of the curves, on which the side friction demand depends.



Figure 1 Analyzed segment of the state road D1

The test rides were carried on a road segment which consists of horizontal curves with radii varying from 80 to 1000 m. Operating speed prediction model for horizontal curves was determined based on the speed data from 10 km long road segment, and the model validation was made with the data from 1 km long segment of the road (Fig. 1). Analyzed road segment is the two-lane state road with relatively low traffic volume (according to [14], the average annual daily traffic was 1377 veh/day in 2011). The rides were recorded during day under optimal weather conditions and free flow conditions, in order to reduce the conditions not related to the geometry of the alignment. Test driver sample consisted of 15 people with passenger cars of different types and ages.

In this study, the values of speeds and radii relevant for analysis, V_{85} and R_{15} , are determined based on data collected from 15 individual drivers [15]. The 85th percentile speed V_{85} is the speed below which 85% of drivers actually drive. The path radii of 15% of drivers are smaller than the 15th percentile radius R_{15} .

4 Analysis and results

Although Croatian guidelines for the road design use the term “operating speed”, it is actually represented as theoretical value named project speed. The question is how much are the values of project speeds consistent with real speeds of most drivers and how the use of project speed affects the side friction demand. Operating speeds determined from the data collected on 10 km long road segment were compared to the project speeds, the comparison between side friction values (demand, supply and design) was made and the operating speed prediction model for horizontal curves was determined.

4.1 Disparity between project and operating speed

The analyzed segment of the road D1 has been designed as a 2nd category state road with design speed of 60 km/h. The values of project speeds in horizontal curves were determined according to Croatian guidelines, for a 2nd category road and actual radii. The actual curve radii on horizontal curves were determined from the road surveying which was made in 2006 by Hrvatske ceste (company for managing, constructing and maintaining of state roads in Croatia).

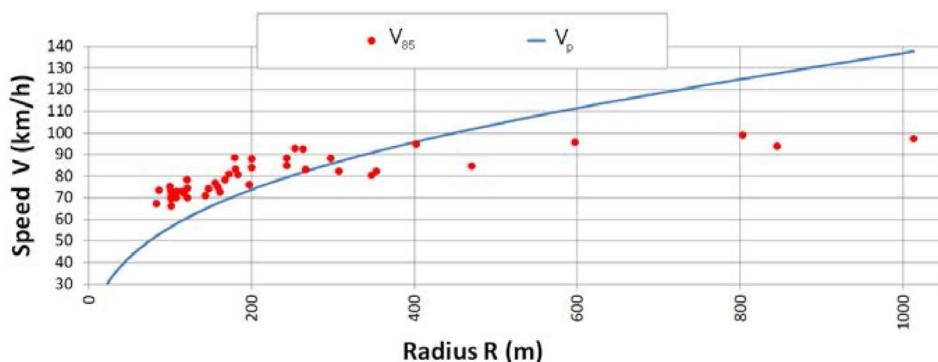


Figure 2 Operating and project speeds in horizontal curves

The comparison between the operating and project speeds is shown in Fig. 2. It can be seen that the operating speed is greater than the project speed in all curves with radii smaller than about 300 m. The project speed is lower than the operating speed which results in insufficient values of stopping sight distances and superelevations optimal for a comfortable ride. Very important elements of the road from a safety point of view are determined based on speeds much lower than actual speeds which may be the cause of accident.

4.2 Side friction demand, supply and design

Differences between operating and project speeds result in exceeding the limiting values of side friction. The side friction demand factors (f_{Rd}) were calculated for actual superelevations in horizontal curves and relevant radii and speeds (V_{85} and R_{15}). The actual radii and superelevations on horizontal curves were determined from the road surveying made by Hrvatske ceste. The side friction demands are compared to the side friction supply (f_{Rmax}) and design side friction factors ($f_{Rdesign}$). The comparison is presented in Fig. 3.

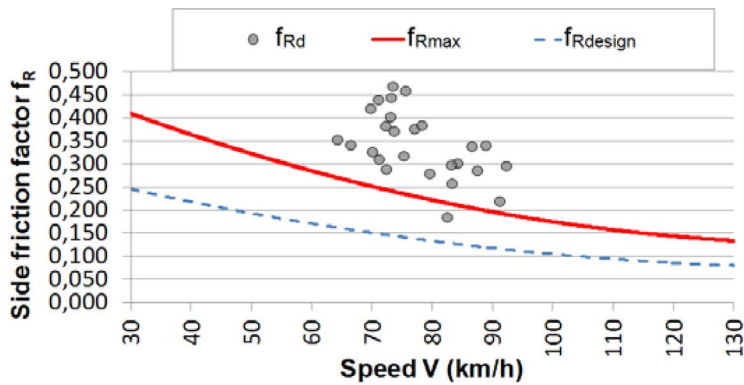


Figure 3 Relationship between side friction demand, supply and design factors

The side friction demands exceed design side friction factors in all curves and they are higher than the peak side friction supply values in almost all curves. This points to the danger of skidding, especially in poor driving conditions such as wet and dirty pavement and worn tires.

4.3 Operating speed model for horizontal curves

The majority of existing operating speed models were made using linear regression with a variety of geometric and traffic characteristics of the alignment [11]. The main independent variables chosen for use were radius of the curve and approach speed (speed at which vehicle approaches a curve). This paper describes a multiple regression procedure to determine a horizontal curve speed model based on data collected on a 10 km long segment of state road D1, with horizontal curve radius (R) and the approach speed (V_{approach}) as independent variables [15]. The model validation was made with the data from a 1 km long segment of the road. Data from 44 horizontal curves ($80 \text{ m} < R < 1000 \text{ m}$) were used for model determination and from 4 curves ($170 \text{ m} < R < 300 \text{ m}$) were used for model validation. Based on the collected data and using a multiple linear regression, the following model was developed:

$$\hat{V}_{85} = 0,023 \cdot R + 0,471 \cdot V_{\text{approach}85} + 35,443 \quad (2)$$

The coefficient of determination of the model is equal to 0,761. The accuracy of the model was also expressed by the mean absolute percentage error, defined by the formula:

$$\text{MAPE} = \left| \frac{\hat{V}_{85} - V_{85}}{V_{85}} \right| \cdot 100\% \quad (3)$$

The overall mean absolute percentage error (MAPE) for the data from the 10 km long segment is 4,2% and the maximum MAPE is 17,2%. Operating speeds derived from the collected data and model predicted speeds in horizontal curves are shown in Fig. 4. It should be noted that the model fits the data well.

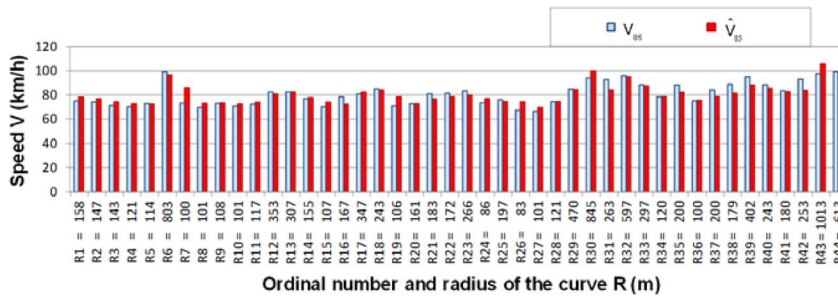


Figure 4 Operating and model predicted speeds in horizontal curves

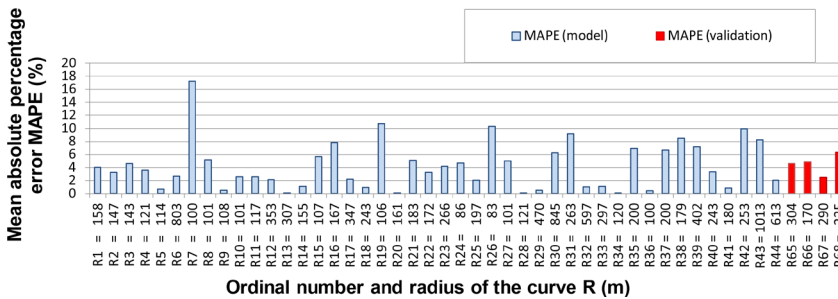


Figure 5 The values of mean absolute percentage error for the model data and validation data

The validation of the speed prediction equation for horizontal curves (2) was performed by comparing the model predicted speeds to field observed speeds from the 1 km long segment of the road. The MAPE value for the validation data is 4,6% and the maximum value is 6,3%. The MAPE values for the data from 10 km long segment (model data) were compared to the values for the data from 1 km long segment of the road (validation data), which is presented in Fig. 5. The MAPE values for validation data are similar to the MAPE values for model data what means that, according to radii and approach speeds, the model predicts accurately the curve speed choice of the driving population.

5 Conclusions

The main factor in the road design procedure is the speed of the vehicle. The relevant speed should be determined primarily based on safety and driving comfort. Speed studies in many countries have found that speeds used in the road design underestimate the actual speeds of most drivers. Most of European countries use operating speed to determine the values of superelevations in curves and stopping sight distances and for the evaluation of speed consistency. The main difference is in the way in which the operating speed is defined and determined. According to Croatian guidelines, the operating speed is a theoretical value defined as project speed. This speed is mostly lower than the 85th percentile speed obtained by field survey which leads to the road elements inconsistent with the actual speeds. That may be a potential cause of an accident. This paper presented an experimental investigation of the drivers' speed behaviour on horizontal curves of two-lane state roads in Croatia. It was found that the operating speed is greater than the project speed in curves with radii smaller than 300 m. Differences between operating and project speeds result in exceeding design side friction factors and peak side friction supply values. These findings indicate the need for changes in the existing road design, mostly in terms of harmonization the relevant speeds that are used in the road design with actual speeds of most drivers.

It is also presented an example of determining the operating speed prediction model for horizontal curves, based on the collected data and using a multiple linear regression. The model was calibrated with continuous speed data measured by an innovative GPS device. Unlike previous spot speed methodologies, GPS allows the determination of locations and values of critical speeds on tangents and horizontal curves. Most previous speed models were based on the assumption that the speed remains constant throughout a curve and that drivers reach their highest speeds in the middle of tangents and reach their lowest speeds in the middle of horizontal curves. The continuous data collected in this study showed that these assumptions, in general are not realistic. The speed throughout a curve doesn't remain constant and locations of the lowest speeds on curves and highest speeds on tangents differ from driver to driver. Although the operating speed model is obtained with a relatively high coefficient of determination and relatively low values of mean absolute percentage errors, it is necessary to include additional independent variables and field data, to make the model more reliable.

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