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RELATION BETWEEN SPEED AND CURVE RADIUS IN ROAD TRAFFIC SAFETY

Road safety, due to a large number of accidents and casualties, has become one of the most important issues of modern society. To achieve and maintain a continuous descending trend of traffic accidents, it is necessary to study the safety problem from the point of interaction of driver, vehicle and the environment (roadway). Previous studies have shown that the most important information perceived by the driver is provided by the road itself. According to these studies, the utmost effect on the driver, when making a decision about how to drive, is made by the elements of road horizontal alignment.

Keywords: road safety, curve radius, spot speed, vehicle path, technical regulations

1. INTRODUCTION

Large number of traffic accidents and above all large number of casualties have resulted in making the road traffic safety as one of the key issues to be tackled in today's modern society. In order to maintain continuous descending trend of accidental deaths and injuries it is relevant to approach the problem from many different angles in terms of interaction between the driver, vehicle and a roadway.

The essence of a so-called feasible approach to safety is best understood in the following saying: prevention is better than cure. The key question remains: how to incorporate safety requirements into the road planning and design process in a way to cause reduction in number of accidents and enhance general road traffic safety?

One can say with certainty that the road planning and design process represents the process which has to provide a high level of quality (high safety and maximal flow) while minimising investments, exploitation costs and environmental damage. In this paper is presented the relation between radius of horizontal curve, as a basic element of horizontal alignment, on one side, and boundary vehicle path and maximum spot speed in the curve, on another side. The emphasis is on the research of a passenger vehicle negotiating the shallow horizontal curve (with a small deflection angle and a radius less than 250 m) in free traffic flow conditions. The shallow curves are set aside to be particularly interesting, taking into account the high rate of road accidents that occur in them [6].

2. LITERATURE REVIEW

The two most important factors that can describe driver behavior in horizontal curves are speed and driven trajectory in those curves. This is particularly highlighted in numerous studies that dealt with driver behaviour in horizontal curves.

Lorenz (Lorenz H.) [10], who had been in the forefront in 1950, analyzed the vehicle movement through the curve of the so-called. "optimal" speed. The author defined this speed as the speed of a free wheel that occurs when driving through the curve. In this case, steering the vehicle through the curve is done exclusively by pressing the accelerator pedal. Analyzing the motion of the vehicle, the author noticed three characteristic vehicle trajectories: the moving vehicle with the optimal speed follows the axis of the conveyor belt; a vehicle moving at a speed greater than the optimal moves towards the outer edge of the conveyor belt; a vehicle moving at a speed less than optimal moves towards the inside edge of the conveyor belt. The author concluded that it is also necessary to use the steering wheel to prevent the vehicle from escaping from the curve. It was found that the driver is also affected by insufficient transparency, the transverse inclination of the car is not adjusted to the average speed of movement, the mismatch of the adjacent elements of the situation plan of the road, etc.

Krebs (Krebs G.H.) [9] was among the first (1973) to analyze the vehicle trajectory in horizontal curves. In his research, he found that in the curves there is a minor or greater deviation of the trajectory from the predicted one in theory. The driven radius is, as a rule, larger than the designed radius for the examined horizontal curve. He showed that the difference is significantly higher in horizontal curves whose radius and the distorted angle are smaller. The author also came up with analytical expressions that connect the driven and designed radius, taking into account the width of the lane and the width of the relevant vehicle. Finally, Krebs concludes that the speed of the curves should be determined by analyzing the radius of the driven trajectory, rather than by analyzing the radius of the designed trajectory.

Kopel (Koppel G.) [7] [8] (1980) showed that differences in the theoretical and actual behavior of drivers are particularly significant in the curvature of a small swivel angle and radius between 50 and 300 m. The author studied the relationship between speed and elements of the situation plan of the road. In his research, he found that there was no solid (unidentified) V-R connection, but this relationship should be viewed from a statistical point of view, with the radius of the curve being significant but not the only parameter that affects the driving speed in the curve. The slightest of the above research is that the connection between the speed and the designed radius is determined, but not between the speed and the driven radius. The author that the phenomenon of the variable value of theoretical (designed) speed as something that needs to be further explored in the future.

In 1993, Doncheva [2] concluded in her research that with the increase in curve characteristics, the number of traffic accidents is increasing. The most important conclusion of her research is that with the increase in the coefficient of dynamic homogeneity, the level of traffic accidents increases. This again stressed that in the modern road design the most important thing is to design a road in which homogeneous uncertainty would be achieved (according to the author, in the 20-40% of traffic accidents the main cause of the accident is exactly the way).

In 1998, Andjus and Maletin [1] investigated the trajectory of vehicles in horizontal curves, especially in radius curves of less than 250 m. The authors conclude that the trajectory in the circumference of the smaller radius curves is more comfortable than the designed trajectory. Such a trajectory, according to the authors, allows the driver to move faster than theoretical proposed speed, and at a higher speed the risk of traffic accidents increases. The authors conclude that the speed is the cause of 53.3% of traffic accidents on two-lane roads.

Spacek (Spacek P.) [11] [12] dealt with the tracing and typing of the vehicle trajectories at the end of the twentieth century. The author proceeded from the fact that when determining the dependence between the behavior of the driver on one side and the path characteristics on the other side, several parameters must be considered. The author emphasizes that it is often the case that research, based exclusively on the analysis of the impact of speed on driving safety, does not prove in its conclusions its starting assumption, since the speed of the cause of traffic accidents cannot be regarded as a mere speed. The author proceeded from the assumption that there is a connection between the geometry of the curve, the trajectory of the vehicle in the curve, and the events of traffic accidents. Experimental research was carried out under the conditions of free traffic flow, on 8 rural road curves of radius between 65 and 220 m. In each curve there were 12 measuring points (on the inside and on the outside of the curve), which enabled tracking of traffic in both directions of movement. During the experiment, the influence of local traffic characteristics on driver behavior in the curves was noticed, in terms of a good knowledge of the road and the prediction of the situations that can be expected on it. The author identified two behaviors as dominant: first, when the driver acted contrary to the applicable regulations and restrictions, and another, when the conduct of the driver was conditioned by the lack of adequate information from his environment. After the experiment was executed, Spacek isolated six different types of trajectories, which included "normal" and "extreme" behavior of the driver (for example, cutting curves).

Fitzsimmons (Fitzsimmons, J. E.) [3] [4] [5] experimentally investigated by means of inductive loops housed in pavement, the vehicle speed and their lateral position in road profile (2012). The study included a one urban and one rural horizontal curve. The results of the study showed that the greatest impact on the trajectory of the motion through the curve has the speed at which the vehicle moves immediately before entering the curve. The author has found that in the horizontal curves of the smaller radius, he drives a significantly larger radius than designed one. In his conclusion, the author pointed to the complex connection between the geometry of the curve, the vehicle, the driver, and the surroundings, as well as that it is necessary to examine in more detail the relationship between the vehicle trajectory and the degree of traffic accidents in the curves.

3. ADEQUATE SPEEDS IMPLEMENTED IN ROAD DESIGN PROCESS AND THEIR IMPACT ON THE ROAD TRAFFIC SAFETY

Speed is one of the key parameters in modern road design process upon which all road elements depend: in cross profile, horizontal alignment and longitudinal profile. It also denotes the level of a road service amidst the familiar traffic load and it is the key indicator in the course of road design development, seeking out solutions and performing the assessment. The speed at the same time represents the initial parameter in defining the elements of a road cross profile.

The problem relating to adequate speeds in a road design process is closely associated with dynamic vehicle routing analysis. Dynamic vehicle routing analyses are of crucial significance when deciding the quality of proposed design solution and are in fact the first and key assessment from the standpoint of both comfort and safety on the roads.

Prevailing part of methods implemented in the course of assessment of dynamic vehicle routing is based on deciding the speed change in terms of implemented plan elements, road profile and traffic load for the provided level of service.

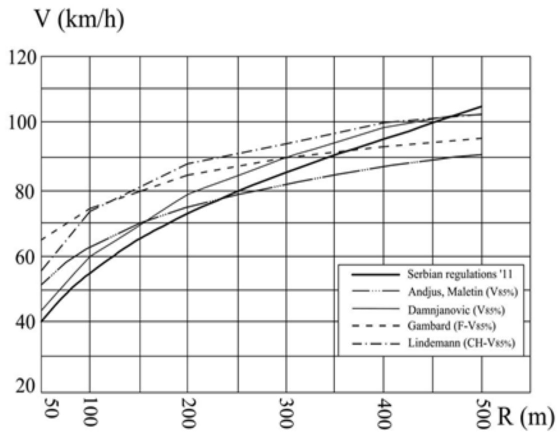

Figure 1. Vehicle speed dependence on a curve radius- research comparison

Source: [6]

In a radius of less than 250 m some significant departures from enforced theoretical speeds have been observed in operating speeds V85%, i.e., operating speeds are significantly higher. This is especially significant from the standpoint of road traffic safety given that the area of small radii is the one where traffic accidents occur the most.

One of the most common design mistakes is in fact application of unharmonised radii of adjacent horizontal curves. Flaws of such a solution are numerous. One of the key drawbacks is discovered in deterioration of change in gradual speed, which brings us to conclusion that road traffic safety is reduced. It is also common to apply the minimal curve radii after an extremely long direction, which brings about a sudden change in speed and quite frequently inability of a driver to adjust his/her speed to conditions prevailing on the road, therefore this suggests direct safety jeopardy on the road.

In the course of designing and formation of round curves it is necessary for a circular arc to be of a sufficient length so as to provide all needed information to the driver on how to navigate the said curve by implementing the adequate speed. As the driving around the curve directly depends on implemented radius and on curve deflection angle (i.e., curve length), for that reason deflection angles recommendable for application have been predefined.

One of the key problems arising in modern designing of roads is how to develop the adequate flow model which will describe in detail real conditions on site and at the same time be simple enough for efficient application in design development phase. Therefore, cibernatic model driver – vehicle – environment has been developed, which helps illustrate various possible situations in a more real fashion which may come up when steering the wheel [6].

4. VEHICLE PATH IN RURAL ROAD CURVES

The impact of these three factors (referred to as D-V-E) is inter-connected, thereby the driver, vehicle and environ make one cibernatic system in which each factor is with its clear defined role: the driver steers the vehicle, the vehicle is the subject of steering, while the environ is the valuable source of information which helps define general system condition.

Control over D-V-E (driver-vehicle-enviornment) is performed by feedback driver-vehicle in the following way: a driver will, owing to his/her senses (here we mean the sense of sight) receive numerous information from the surrounding area in the course of driving which he/she processes further and after which he/she makes a final decision on steps to be undertaken. As a result of such steps, and naturally in line with vehicle possibilities at the given moment of time, variation in vehicle travelling occurs which the driver both experiences and controls through its senses by means of a negative feedback. The theory behind all this is that a driver with the help of a feedback receives information on consequences of the action which he/she had previously taken. Driver's actions are not only affected by one element in the surrounding, but rather by many other elements from the same surrounding. In addition, time component changes as well in the system apart from spatial one, and for that reason the system is called a closed cibernetic system [6].

Term ideal vehicle path implies vehicle radius supported by the radius which fully meets the radius of the design path.

Previous researches have shown that in curves whose radius is less than 250 m and which are of small deflection angle, vehicles are manouvered at higher speeds when compared to ones obtained in analysis of theoretical dependence V-R (theoretical Vvd), which is presented in technical regulations.

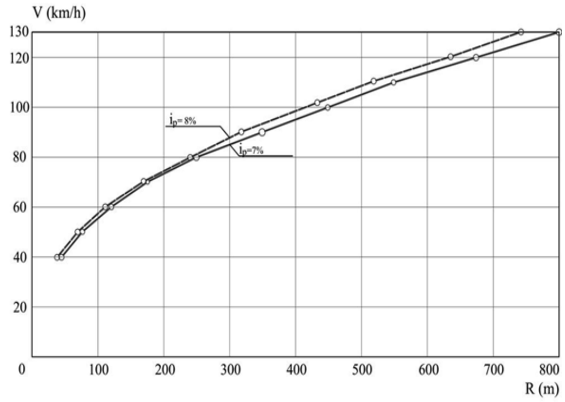

Figure 2. Theoretical dependence of variable design speed on horizontal curve radius

Source:[Serbian technical regulation]

Of special importance is the fact that the area of smaller radii is the one where large number of car crashes occurs - Ns. By analysing the aforementioned, the conclusion has been drawn that the design vehicle speed around the curve is to be decided based on vehicle path radius (expected), and not based on a radius of ideal (design) path.

5. CONCLUSIONS

The significance of analysing the spot speeds is best reflected in defining the connection between operating speed - driven radius, which shows that in the area of small radii (R<250 m) there are some significant deviations from the theoretical connection V-R, which is applicable in the most of the technical regulations. Some significant differences in values between vehicles spot speeds and those assumed in the theory have been established in the past. With reference to future research, in order for determining the methodology of broader significance from the standpoint of road traffic safety, the following recommendations can be emphasized [6]:

- perform experimental research with an aim to establish the impact of adjacent curves onto drivers' behavior around such curves;

- perform additional experimental researches with regards to speed under wet road conditions so as to eastblish in a more accurate manner the impact of the wet road onto the driving speed, which would be later implemented onto broader road network;

- incorporating conclusions drawn from these research into the process of Road Traffic Safety Audit, as an integral part of check lists used in the process.

Impelmentation of recommendations above could lead to the intended aim which is implementation of results of these researches into the technical regulation for designing of new road sections, reconstruction and rehabilitation (especially in the process of identifying black spots and "hazardous" road positions).

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