Road Design Consistency Analysis for Roads on Serbian Road Network

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Abstract

The objective of this paper is to consider a possibility to use the geometric design consistency analysis as a method to evaluate safety of roads on the Serbian road network. Lack of maintenance due to the multiyear economic crisis resulted in a poor condition of over 50% of the arterial and regional road network with modern pavement. Furthermore, the safety of Serbian roads, according to the number of accidents and the kilometers traveled on the entire road network, is two times lower than the road safety in Western European countries. Key activities of the Serbian road industry in the years to come will be oriented toward rehabilitation of the road network, improvement of their safety, and compliance with environmental protection requirements. Serbian road design regulations are almost 25 years old. In spite of the fact, the design practice observes the state-of-the-art road design methods, including analysis of design speed profile and required sight distance profile as basic criteria in the design of some road elements. Thus conceived design process may be satisfactory for the design of new road sections. However, for evaluation of safety of the existing road sections it is necessary to define a specific methodology that would be based mostly on the already accepted design practice. The paper considers use of speed profile and available sight distance profile, which are accepted in the design practice, as basic indicators of the geometric design consistency of road elements. Samples given in the paper show comparison of the presented method with the practice applied in other countries. The presented method, as a theoretical model, represents a basis for any future research. Further research would call for field measurements and statistical data analysis in order to verify the hypotheses presented in the model and to calibrate the model according to the conditions on the Serbian road network.

1. Introduction

Serbian network of rural roads may be classified by geopolitical criterion into arterial, regional and local roads. With respect to the area and population of Serbia, the total length and density of the road network are satisfactory and meet the applicable standards in the EU countries.

According to the available official data on International Roughness Index (IRI), over 50% of the arterial road network is estimated to be in poor condition. Given the time-inconsistent measurements of road roughness and the poor maintenance, it is possible to estimate that barely 30% of arterial road network is in good condition.

Geometric indicators reveal that about 50% of arterial roads have carriageway width over 3.25m. On the other hand, the minimum radius of horizontal curve of 120m (60km/h) on a section is present on about 67% of the arterial road network, while being smaller on the rest of the network.

Data on Serbian road network safety are available only in form of average values by road routes. According to data for 2001, the average number of accidents per 1 million vehicle-kilometers is 0.87 on two-way roads, and 0.40 on motorways. The average values are multiply higher than those in the Western European countries.

As shown above, we may conclude that Serbia is yet to face the extensive modernization and improvement of its road network, particularly regarding condition of pavement and road safety. Therefore it would be necessary to reconsider condition of road sections from the safety aspect and accordingly adjust the scope of interventions on them.

Unfortunately, the status of design-related legislation in Serbia is not a single step ahead of the road network condition. The current regulations governing the design of non-urban roads [1] were enacted in 1981. In spite of that, the design practice follows the modern road design methods that include analyses of design speed profile and required sight distance profile as the basic criteria for the design of specific road elements. Such design process can be satisfactory when designing new road sections, but as far as evaluation of safety on the old road sections is concerned, it would be necessary to define a specific methodology that would rely on the already accepted design practice as much as possible.

2. Background

The current road design regulations do not explicitly stipulate definition of geometric design consistency as a measure of road section safety. However, they partly deal with some individual elements regarding this issue. The basic value for definition of geometric elements is a design speed. It is defined based on consideration of relation between the previous speed (in function of road class and terrain category) and the expected speed (function of bendiness and carriageway width). As for geometric design consistency, the regulations stipulate the values of transition curve parameters, and a favourable relation between the applied adjacent radii of a horizontal curve. The regulations further stipulate the minimum length of stopping sight distance as a design speed function.

In the design practice in Serbia, the methods and procedures for preparation of design documentation are defined in 1993 “Road Design Methodology” [3]. This document unambiguously defines steps in preparation of investment-technical documentation and the design process structure, including activity schedule. The Road Design Methodology specifies definition of design elements based on “variable design speed diagram”. The variable design speed diagram is a theoretical model of vehicle’s running speed in a free traffic flow on a road section and depends on the horizontal and vertical elements of the road alignment. The Road Design Methodology also stipulates analysis of the required sight distance profile and the available sight distance profile in order to assess the applied geometric design.

The Road Design Methodology refers to design of new sections, and it is thus necessary to define, on such theoretical grounds, with minor modifications, a new methodology for assessment of safety. Many studies have already confirmed a great influence of geometric design consistency on safety. The geometric design consistency can be assessed in different ways: with respect to driver’s workload required to perform a certain task, with respect to inter-relation of the adjacent geometric elements or with respect to speed change conditioned by road geometry.

The difference between the expected driving speeds on adjacent elements, i.e. the speed reduction level to be achieved, has proved to be a reliable indicator of potentially higher incidence of traffic accidents. On the other hand, the driver’s ability to perceive road conditions and identify what kind of maneuver is expected from him/her affects safety to a great extent. In these terms, consideration of the available sight distance and the required sight distance can be used to assess safety of a road section.

In compliance with the design practice, the concept of the presented road safety evaluation model is based on analysis of the variable design speed profile and the required and available sight distance profiles.

3. Basic Assumptions of the Proposed Safety Evaluation Method

The proposed safety evaluation model considers driving-dynamical and optical analyses of the relevant road section. The driving-dynamical analyses take into consideration the variable design speed profile. The optical analyses deal with the required sight distance profile and the available sight distance profile. The pavement runoff analysis, through the resulting pavement gradient diagram, is not included, as we imply that any design (for rehabilitation, reconstruction) will bring it to a satisfactory condition.

3.1. Driving-Dynamical Analyses – the Resulting Variable Design Speed Profile

The resulting variable design speed profile implies superposition of the variable design speed profile on the site plan and on the longitudinal profile. The variable design speed profile on the site plan implies a constant driving speed in a round curve. Such speed is derived from the basic theoretical formula:

$$V_p = \sqrt{127 \cdot R \cdot (\max\ e + \max\ f_{tr})}$$, e – superelevation, f_{tr} – transverse friction coefficient

On the other horizontal elements: straight sections and transition curves, the vehicle running speed is assumed to undergo a linear change. Acceleration and deceleration values are taken as identical: a=d=0.8 m/sec^2. Here we may raise a question of the maximum expected speed to be used for straight sections and curves of larger radius. When designing new road sections, according to the current design regulations, the maximum speed value is taken to be the design speed value increased by 20km/h. When designing new sections, this may be right, but the goal is to make design elements such to have the speed range of 20km/h, which is acceptable from the safety aspect. However, for the existing sections, one may expect a much wider speed range. On two-way roads in Serbia, the maximum allowable speed is 100km/h. However, we may bring up the question of justifiability of taking this value as the maximum one for the roads of a lower class. The final SAFESTAR report [7] gives several models from different countries for definition of speed on straight sections. These models make it evident that several factors may affect the expected speed. These are particularly: traffic lane width, shoulder width, longitudinal gradient, bendiness, average cross fall, sum of elevation changes, etc. Different studies have shown varying importance of the impact of particular geometric elements on driving speed on a straight section. Since Serbia did not perform many studies in this area, the presented model proposes that the maximum speed be defined based on a functional classification rather than on impacts of particular elements. The proposed maximum speed values are given in Table 1.

Functional classification	max V_r
Collector road	90 km/h
Link road	100 km/h
Long-distance road	110 km/h

Table 1 Maximum speed subject to function of a road within the network

The impact of longitudinal gradient on driving speed is much lower than the impact of site plan elements. In this sphere, there is a substantial agreement between studies performed in different countries. Figure 1 shows the driving speed with respect to longitudinal gradient according to the regulation proposal from 1991.

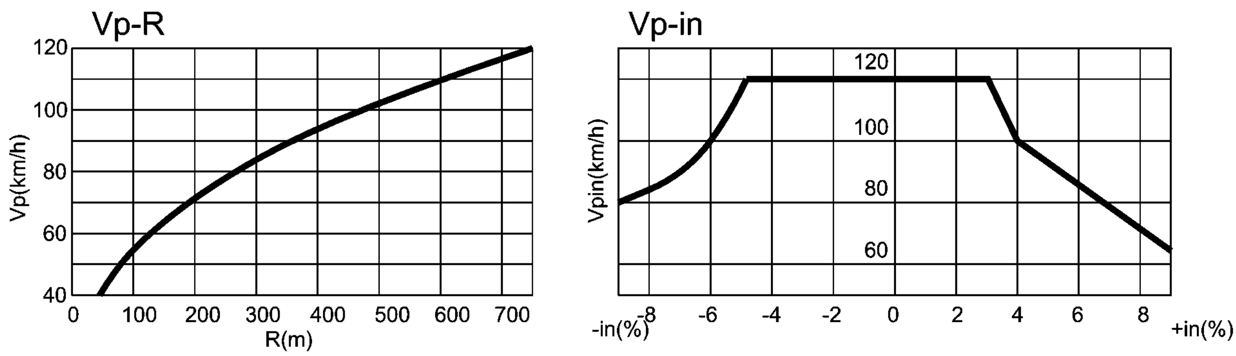

Fig. 1 Dependence: vehicle speed – radius and vehicle speed - longitudinal gradient

The presented dependence of speed on particular road design elements is used to develop the resulting design speed profile that shows the expected driving speed at each point of the road section.

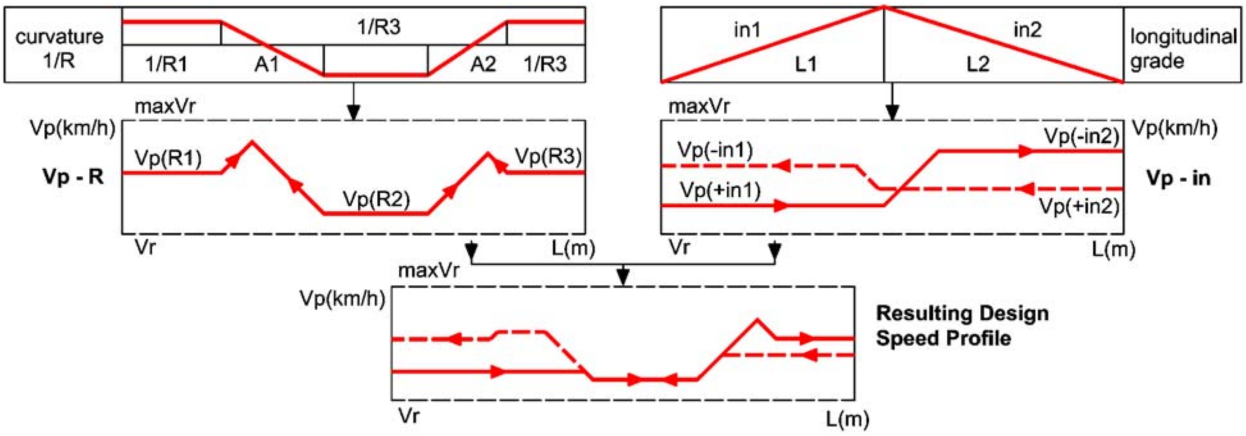

Fig. 2 Development of the resulting design speed profile

The developed design speed profile is further applied to consider speed difference on the adjacent geometric elements according to the generally accepted criteria:

Speed difference ΔVp	Design quality
< 10 km/h	good
10 – 20 km/h	fair
> 20 km/h	poor

The resulting design speed profile is analogous with the 85th percentile speed ($V_{85\%}$) diagram.

3.2. Optical Analyses – Required and Available Sight Distance Diagrams

Generally speaking, the available sight distance at each point on the road shall be sufficient for a vehicle running at the expected speed to safely stop before an obstacle that gets in its way. One may derive therefore that the required sight distance diagram shall be developed using the above-described design speed profile. As widely known, the formula used to calculate the required sight distance is made of the distance traveled during the reaction time and the distance traveled while stopping the vehicle by mechanical brake system.

$$RSD = \frac{V_p \times t_r}{3.6} + \frac{V_p^{\;2}}{254 \times \left(f_t + w_k \pm i_n\right)}$$

V_p – Variable design speed
t_r – Driver reaction time
f_t – Coefficient of tangential friction
w_k – Coefficient of rolling friction
i_n – Longitudinal gradient of the road

The required sight distance diagram shall be compared with the available sight distance diagram created based on the existing geometric elements of a road on site plan, longitudinal profile and cross profiles. At points where the required sight distance has not been met it is necessary to take adequate building measures.

4. Comparison with Other Models

The road design consistency analysis through analysis of the 85th percentile speed regression model is often used. The presented model does not greatly differ from the other models by its concept. The crucial difference is in consideration of the theoretical model of speed-radius dependence with respect to the experimentally identified dependence. There are no many studies in this field in Serbia. One of the essential studies in the field of the 85th percentile speed dependence on road geometry elements in Serbia is the study by Prof. Damjanovic [6]. The objective was to determine normative values of speed in free flow that would serve to define road geometry elements. The experiment was carried out in such a way that the drivers had been instructed to strictly observe the road geometry, and to drive at the maximum safe speed allowed by the road geometry elements. Figure 3 shows the dependences of the 85th percentile speed on horizontal radii that are used in different countries [9], the dependence from the research work of Prof. Damjanovic, and the theoretical model discussed in this paper. From the diagram above one may see that the curve of theoretical dependence discussed in this paper and the curve of dependence from the work of Prof. Damjanovic match by their shapes, which points to similar postulates, particularly the way of driving. Dependence curves of the other countries show much higher speeds at radii less than 250m, and lower speeds at larger radii.

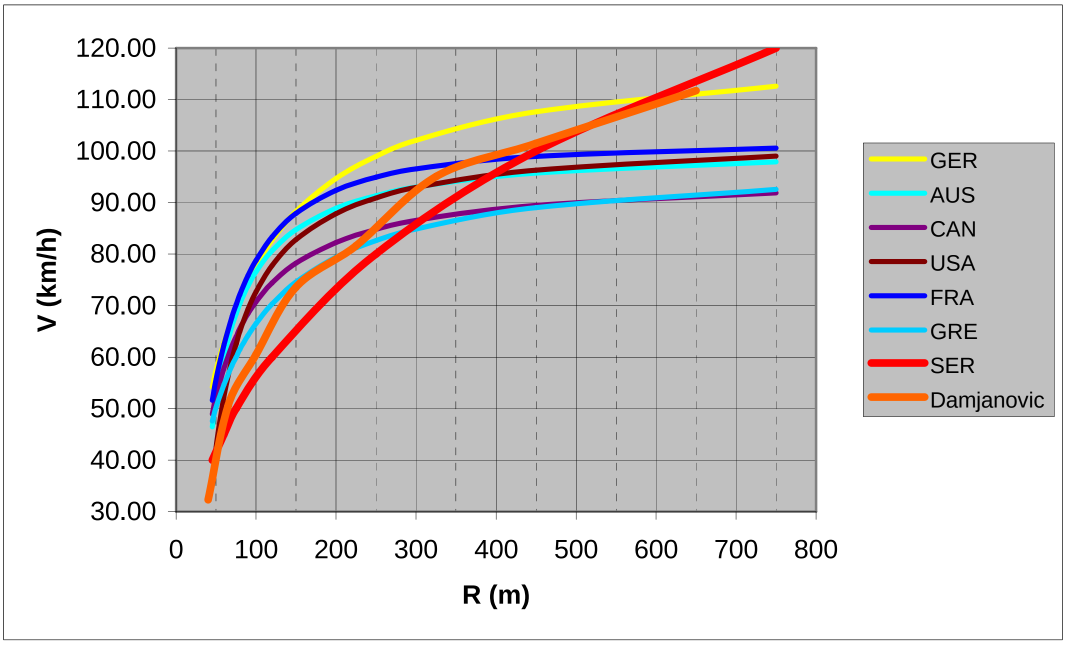

Fig. 3 Diagram showing dependence of the 85th percentile speed on horizontal radii

The differences can be explained mainly because in reality the vehicle trajectory does not fully coincide with the designed geometry, particularly not in smaller radii and curves with smaller deviation angle. Furthermore, the difference also occurs because wet pavement is taken into account in theoretical dependence. In larger radii, the difference occurs mainly due to lack of driver's motivation to drive at the maximum speed, and due to speed limit. From all this we may conclude that it would be necessary to define experimental dependence of speed on horizontal radii for roads in Serbia. For comparison with presented method on the test section, Interactive Highway Safety Model – IHSDM is chosen.

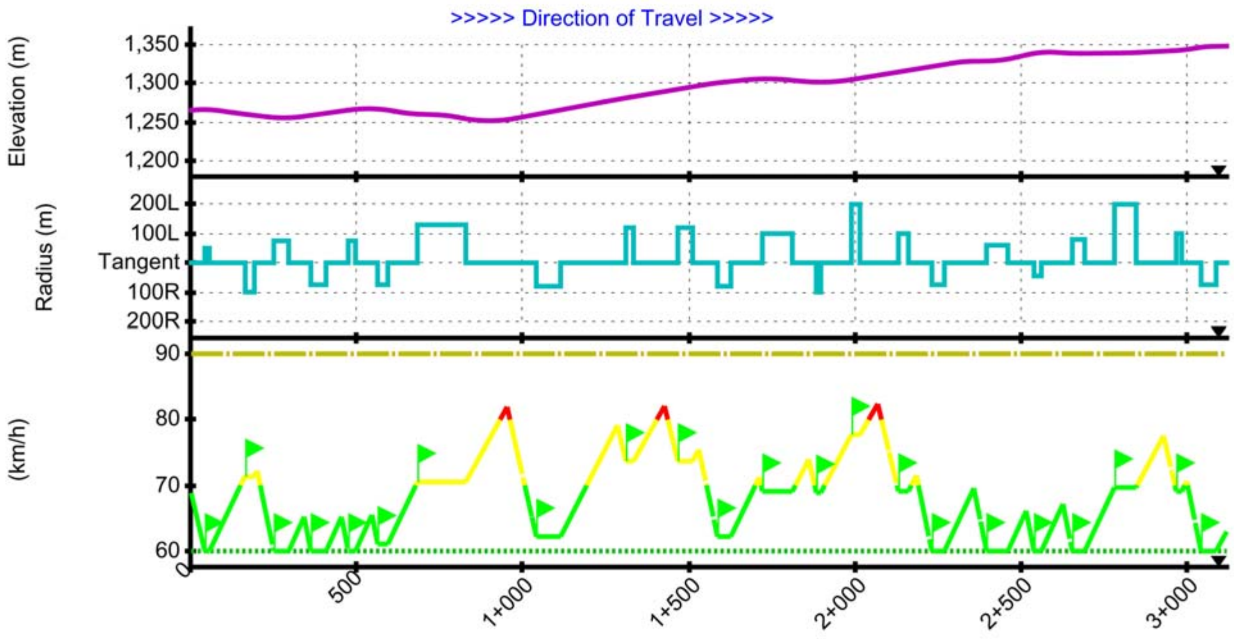

Fig. 4 IHSDM – Design consistency analyze of test section

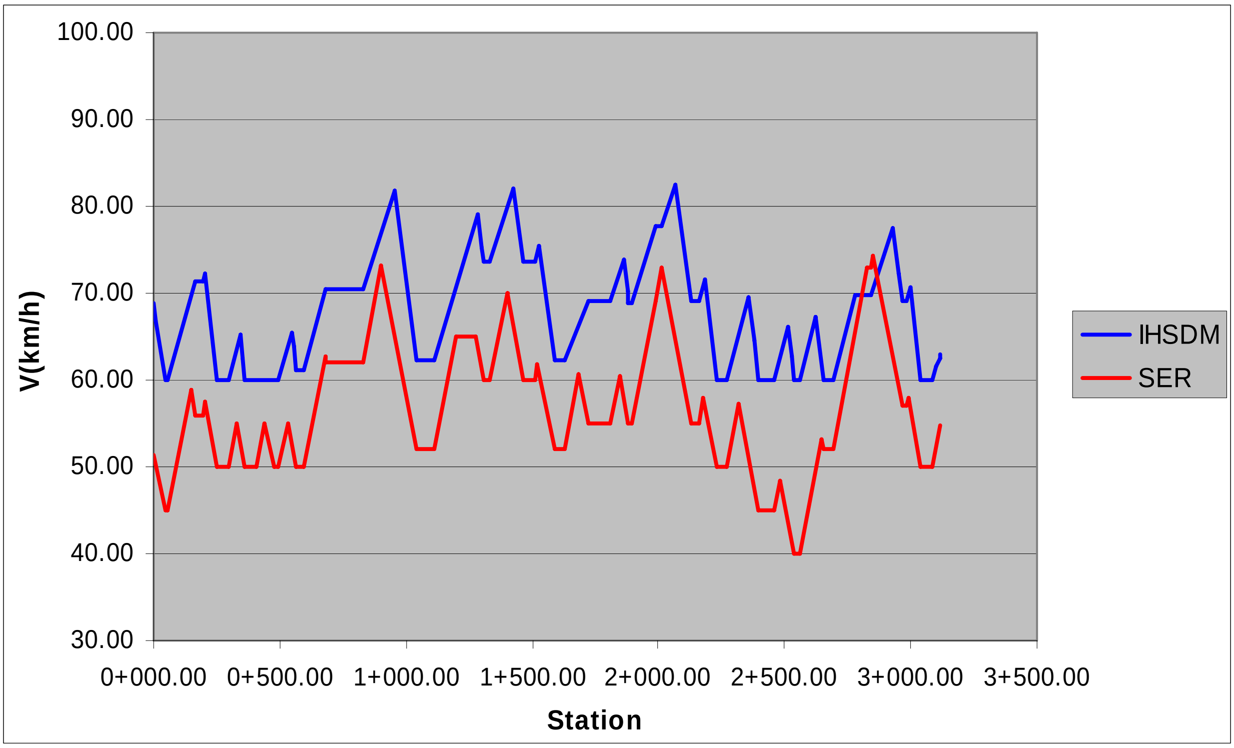

Fig. 5 Comparison between IHSDM speed model and presented speed model

From the fig. 5 one may see that both diagrams match by their shapes but the difference is in speed values.

5. Conclusion

The presented model can serve as a basis for further research. Since there is a significant difference between the theoretical dependence between speed and horizontal radii and the dependences experimentally defined in other countries, the presented model may give only some of the indication on safety condition in specific cases. It is necessary to perform research and experimentally define dependence of speed on road geometry on the Serbian road network. In further research it would be necessary to perform field measurements and statistical analyses to confirm the model postulates and to calibrate the model according to the conditions identified on the Serbian road network.

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