THE ASSESSMENT OF ROAD GEOMETRY PARAMETERS ON LOW-VOLUME ROADS IN LITHUANIA

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ABSTRACT

Gravel Roads Paving Program has been started since 1998, however, it was determined that after reconstruction 4.7 % of gravel road sections became potentially dangerous. One of the main disadvantages of this program is a slightly changed or entirely unchanged horizontal alignment of roads. During the reconstruction the road pavement is strengthened, the gravel surface is replaced by asphalt pavement. This enables to increase the speed limit but based on design rules the design speed remains unchanged. Investigation of horizontal alignment of 30 regional roads was carried out in order to assess compatibility of the horizontal alignment elements and their correspondence to traffic safety. It was determined that compatibility of the horizontal alignment elements is fair, and the calculated operating speed v_{85} is 10–20 km/h higher than the design speed v_d. It was also determined that compatibility of the horizontal alignment elements of low-volume roads in most cases is fair. Dynamic consistency of roads is poor. Analysis of vertical alignment showed that the stopping sight distance meets the requirements in all the elements of vertical alignment, whereas, the passing sight distance meets the requirements only in 8.2 % of all elements where the design speed v_d = 70 km/h.

1. INTRODUCTION

Design, reconstruction, building, repair and maintenance of roads are related to the implementation of strategies of traffic safety policy. In this respect the largest responsibility lies on road designers who, during the process of design, have to combine the objectives of many interested groups (customers, future road users, road maintenance enterprises) in order to obtain economic and social efficiency over the lifetime of road.

In Lithuania motor roads are designed in accordance with the requirements set in normative documents. After the restoration of independence of Lithuania in 1990, the first Lithuanian regulatory document on road design was issued only in 1996, i. e. Road Design Standards and Rules. This document classified Lithuanian roads not only into categories but also into groups according to the average annual daily traffic, position in respect of built-up areas and parameters. The design speed was selected according to the road category, also for each road category the speed limit was set and the 85th percentile operating speed was introduced for individual road sections depending on the width of carriageway and the curvature of alignment. Geometric parameters of the alignment elements were designed according to the local position of road, its category, the speed limit and the design speed, also the speed v_{85}.

In 2002 the Construction Technical Regulations came into force where the principle of road classification remained the same – according to the average annual daily traffic. In the Construction Technical Regulations standardization of the speed limit, the operating speed v_{85} and the assessment of the curvature of alignment were refused. Still, it contained the footnote that the design speed shall be selected based on the road building and reconstruction conditions and complexity of location. Having changed the document the number of road categories was reduced and the design of roads became more simplified – geometric parameters of the road alignment elements were selected only depending on road category and design speed. Having refused the concept of the 85th percentile operating speed the individual road sections had not been assessed.

In 2008 the Road Technical Regulations (RTR) was adopted. It classifies roads according to the road significance and the average annual daily traffic. In those regulations the number of road categories was increased but the principles of road design were not changed. Besides, the annexes to this document gave a new classification of roads according to their function. It says that the road network shall serve three functions: through, distribution and access. The RTR also points out that when planning or designing roads every attempt shall be made to adapt road to serve only one function [1].

Low-volume roads in Lithuania correspond to regional roads of national significance with the average annual daily traffic less than 10000 vehicles per day. Depending on road category and pavement type the design speed could be 70 or 90 km/h. Gravel roads in Lithuania make 35.7 % of the total road network of national significance [2].

In 2002 the Road Maintenance and Development Program was started to be implemented the aim of which – to evenly develop road network in the regions and thus to reduce the social and economic differences. A part of this program was intended for paving of gravel roads. The aim of Paving of Gravel Roads Program is to reduce a number of gravel roads to 30 %. Investigations by Gintalas showed that when implementing the mentioned program and making road reconstruction projects the horizontal alignment of roads is only slightly changed or entirely unchanged since any change of alignment line requires alienation of a certain part of private land and this would result in a longer project preparation and approval and in the increased project cost [3–5].

When reconstructing gravel roads the pavement structure is strengthened and the asphalt pavement is laid. Based on the Traffic Rules of Lithuania the speed limit on rural roads with asphalt pavement is 90 km/h, with gravel pavement – 70 km/h. It follows that after road reconstruction the same parameters of road alignment are left but the speed limit is increased from 70 km/h to 90 km/h. Such increase in speed without changing road alignment parameters can result in road accidents.

The experience of European countries shows that based on the sustainable safety principles, when implementing a preventive traffic safety strategy, roads must be studied according to their function and geometry. The approach of sustainable safety was created in Netherlands in 1990. It has two aims: to as much as possible reduce driving errors and to mitigate accident consequences. The system of sustainable safety could be formed with the help of the following sustainable safety principles [6]:

- functionality: functionality of the road system is important in the fact that the real use is consistent with the planned one;
- homogeneity: homogeneity of the road system is necessary to avoid large differences in speed, driving directions and road users;

- predictability: to seek for the same type of road alignment having a unique combination of characteristics and limited number of road types in order to avoid mess and to increase perception possibilities.

On low-volume roads where the average annual daily traffic is less than 10000 vehicles per day and the speeds are up to 90 km/h many accidents occur, this means that they are not safe, traffic conditions are bad and they do not serve their function – access. Therefore, it is necessary to determine factors which would help to attribute roads to low-volume roads and to describe the effect of their geometric parameters on traffic safety.

2. LITERATURE REVIEW

Based on the analysis of RTR a summary scheme of the classification of roads of national significance was made (Figure 1) showing that the low-volume roads correspond to the roads of regional significance which shall ensure the minimum level of traffic quality and shall serve the access function.

Having determined relation between road function and road category it is obvious that the current road classification procedure prevents from reaching the aim to adapt road to serve only one function (Table 1). Therefore, it is suggested to supplement the current Lithuanian classification of roads of national significance with a new classification by road function in order the road would serve only one function.

Traffic conditions on low-volume roads were studied in accordance with sustainable safety principles. Aiming at safe traffic conditions on roads the study was carried out on how the road alignment elements affect traffic safety.

Table 1 – Classification of roads by function and significance

Roads by function	Category of road	Classification by significance		
		Main roads	National roads	Regional roads
Through	AM	+	-	-
	I	+	-	-
	IIa	+	-	-
Distribution	Ia		+	-
	II	+	+	-
	IIa	+	+	-
	III	+	+	-
	IV*	-	+	-
Access	IV	-	+	+
	V	-	-	+
	Va	-	-	+

When designing new road or reconstructing the existing one the parameters of road alignment elements are selected according to the road category and the design speed v_d. The minimum curve radii of horizontal alignment and the length of tangents between curves are selected according to the road category. There are no requirements to the compatibility of tangent and curve [1].

In road design not only the design speed v_d but also the permissible speed v_L and the operating speed v_{85} is used. Certain indices were developed to assess compatibility between the road elements or to predict the operating speed v_{85}. Cafiso investigations showed that the estimated average operating speed v_{85} can help to best of all assess driving speed on long tangents of roads [7].

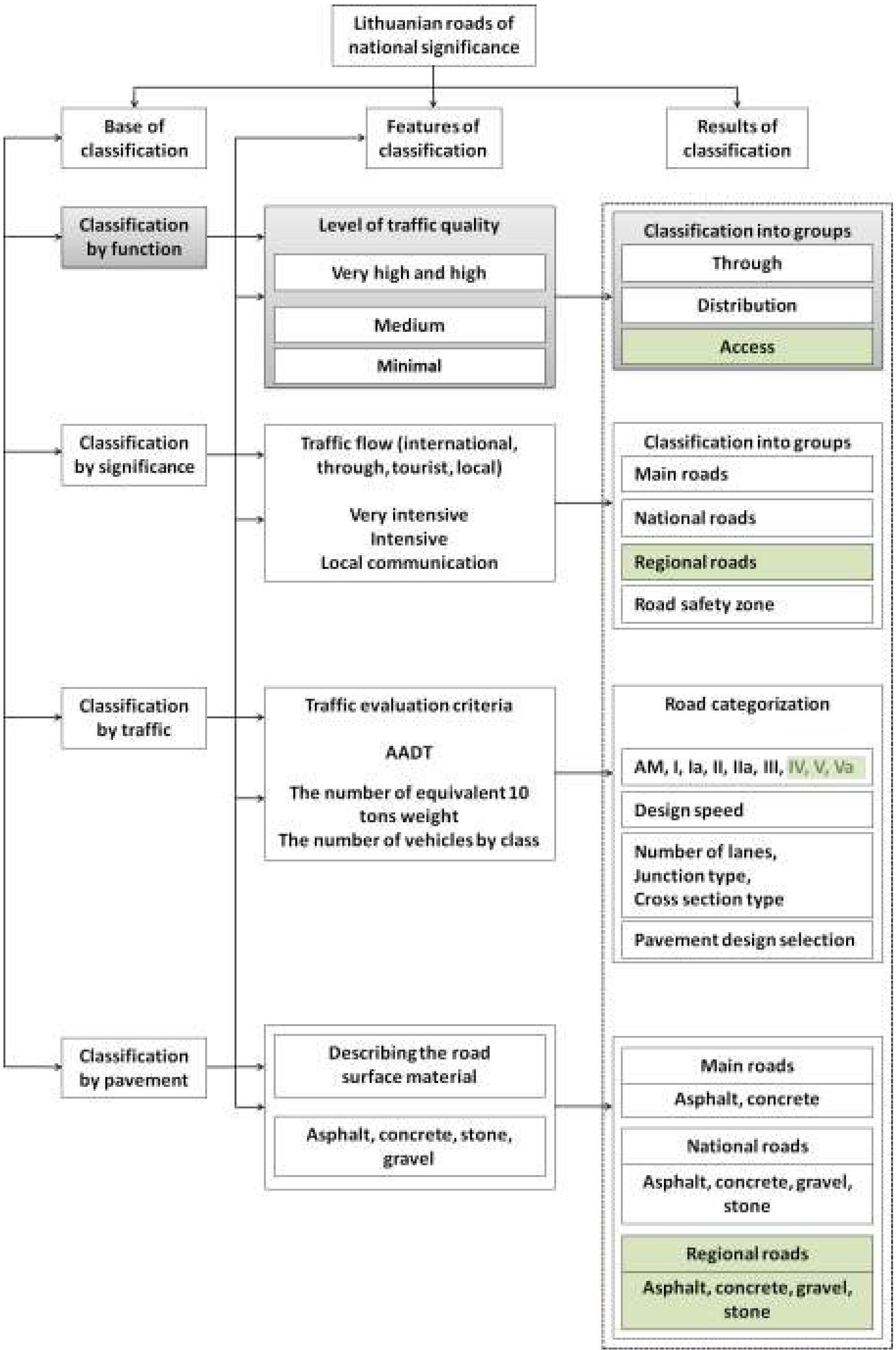

Figure 1 – Scheme of the classification of Lithuanian roads of national significance

Selection of driving speed is partly dependent on horizontal alignment and compatibility of its elements. Gintalas determined that incompatibility of the horizontal alignment elements is increased if there is no successive transition between the elements [5]. Investigation results proved that incompatibility of the horizontal alignment elements leads to unsafe driving due to potentially large speed variations. Investigations by Fitzpatrick showed that geometric compatibility of horizontal alignment line is one of the attributes of safe traffic [8].

Investigations by the scientists of various worldwide countries on two-lane roads to determine the importance of the horizontal alignment elements (curvature change, length of curve, height of elevation, width of traffic lane, width of shoulder, sight distance, gradients) showed that the speed variation and a number of accidents are the best described by the Curvature Change Rate CCR_S [9]:

$$CCR_S = \frac{\frac{L_{P1}}{2R} + \frac{L_A}{R} + \frac{L_{P2}}{2R}}{L} \cdot \frac{180}{\pi} \cdot 10^3 = \frac{|\gamma| \cdot 57330}{L} \text{, deg/km,} \quad (1)$$

where $L = L_{P1} + L_A + L_{P2}$ – length of curve, m; L_A – length of circular curve, m; R – radius of circular curve, m; L_{P1}, L_{P2} – length of the first and the second transition curve, m; γ – turning angle of road alignment, deg.

On a basis of these investigations regression equations of the speed v_{85} have been developed:

- when the road‘s longitudinal gradient i ≤ 6 % and curvature change rate CCR_S ≤ 1600 gon/km,

$$v_{85} = 105.31 + 2 \cdot 10^{-5} \cdot CCR_s^2 - 0.071 \cdot CCR_s \text{,} \quad (2)$$

- when the road‘s longitudinal gradient i > 6 % i and curvature change rate CCR_S > 1600 gon/km,

$$v_{85} = 86 - 3.24 \cdot 10^{-9} \cdot CCR_s^3 + 1.61 \cdot 10^{-5} \cdot CCR_s^2 - 4.26 \cdot 10^{-2} \cdot CCR_s \text{.} \quad (3)$$

where CCR_S – the total curvature change rate of the existing or planned road alignment.

To better implement the designs of new and existing roads in terms of traffic safety the method of three traffic safety criteria have been developed which allows to more effectively assess the design level of two-lane roads [9, 10]:

- design speed consistency (Safety Criterion I (SC I)) – consistency of the design speed v_d is identified by comparing the selected design speed v_d with the speed v_{85} in each element of the road alignment;
- operating speed consistency (Safety Criterion II (SC II)) – the speed v_{85} shall be consistent between two successive road elements;
- driving dynamic consistency (Safety Criterion III (SC III)) – criterion of driving consistency and cost-efficiency which relates side friction assumed with respect to the design speed to that demanded at the speed v_{85}.

Based on the Safety Criteria compatibility of only the horizontal alignment elements to safe driving conditions is assessed, however, this method is not suitable for assessing vertical alignment of roads.

In order to ensure safe traffic conditions on vertical alignment the sight distance requirements shall be met: stopping sight distance and passing sight distance [10]. According to the Road Technical Regulations of Lithuania the elements of the vertical alignment are designed taking into consideration the design speed v_d and the sight distance.

In Lithuania the stopping sight distance and passing sight distance shall be ensured for the vehicles driving at the design speed v_d on a road segment with the longitudinal gradient i.

The minimum length of crest vertical curve is defined by the sight distance which is usually acceptable from the point of view of safety, comfort and appearance. The stopping sight distance is calculated from the following dependencies:

$$L = 2 \cdot S - \frac{200 \cdot \left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A}\text{, when } S \geq L; \tag{4}$$

$$L = \frac{A \cdot S^2}{100 \cdot \left(\sqrt{2 \cdot h_1} + \sqrt{2 \cdot h_2}\right)^2}\text{, when } S \leq L; \tag{5}$$

where: L – length of crest vertical curve, m; S – sight distance, m; A – difference in the gradients of vertical tangents, A = $|G_2-G_1|$, G_1, G_2 – gradient of vertical tangents, %; h_1 – height of driver‘s eyes (for a visible stopping distance 1 m, for the passing sight distance 1 m), m; h_2 – height of obstacle on the road (for a visible stopping distance 0.15 m, for the passing sight distance 1.2 m), m.

On sag vertical curves traffic safety is affected by the distance illuminated by vehicle lights. Determination of the distance illuminated by vehicle lights is important for the vehicles driving in a dark period of the day. Illuminated distance is identified from the following dependencies:

$$L = \frac{A \cdot S^2}{200 \cdot \left(H + S \cdot \tan\beta\right)}\text{, when } S \leq L; \tag{6}$$

$$L = 2 \cdot S - \frac{200 \cdot \left(H + S \cdot \tan\beta\right)}{A}\text{, when } S \geq L; \tag{7}$$

where: L – length of sag vertical curve, m; S – illuminated distance, m; A – difference in the gradients of vertical tangents, A = $|G_2-G_1|$, G_1, G_2 – gradient of vertical tangents, %; H – height of vehicle lights above the carriageway (H = 0.60 m), m; β – change in the radius of vehicle lights (β = 1°), in degrees.

The passing sight distance is a distance which shall be sufficient to make a passing maneuver. On vertical curves it is allowed to pass if there is a sufficient visibility. On sag curves the passing sight distance is not studied, since visibility here is ensured according to the distance illuminated by vehicle lights. The passing sight distance is calculated by the following formulas:

$$S_{AM} = \frac{L + \frac{864}{A}}{2}\text{, when } S > L; \tag{8}$$

$$S_{AM} = \sqrt{\frac{864 \cdot L}{A}}\text{, when } S < L; \tag{9}$$

where: A – difference in the gradients of vertical tangents |G2-G1|, %; S_{AM} – safe passing sight distance; L – radius of vertical curve, m.

3. OBJECT AND INVESTIGATION METHODS

To select investigation objects the territory of Lithuania was divided into three zones according to the map of vertical zoning (Figure 2): zone I – Samogitian (Zemaiciu) Highland; zone II – Higher Lithuania Lowland; zone III – Higher Lithuania Highland.

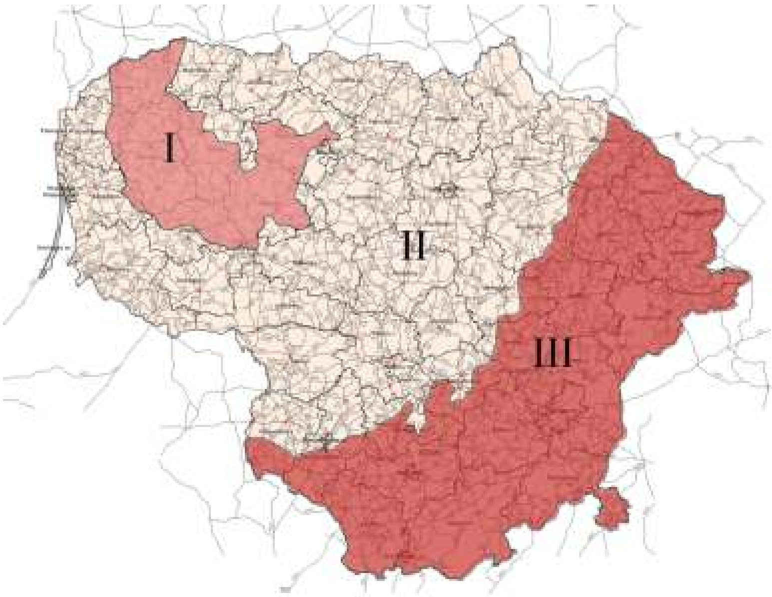

Figure 2 – Regioning of the territory of Lithuania by the vertical zoning of relief

30 roads of regional significance were selected located in those three zones. The total length of roads made 561 km. On the selected roads the spatial views of horizontal alignment line were identified which were further used to determine:

- parameters of the elements of horizontal alignment line: length of tangent, radii and lengths of horizontal curves;
- parameters of the elements of vertical alignment: lengths and gradients of tangents, radii and lengths of vertical curves.

Investigation was carried out in the Lithuanian LKS 94 coordinate system and in the Baltic Heights system using GPS technologies. A spatial line of road alignment was measured by the Leica 1200 GPS device with the use of which data was acquired by the RTK (Real Time Kinematic) technology. Measurements were taken by a rover fixed to the vehicle at a 2 m height above the carriageway. Signals of satellites were recorded every 20 m driving by the study roads at a speed of 20–50 km/h. In this way the 3D coordinates of the carriageway surface were measured within the vehicle movement trajectory. With the help of AutoCad Civil3D tools the digital terrain models of the study roads were developed. In those models a spatial line of road alignment was constructed. When designing a spatial line of road alignment into horizontal and vertical planes the horizontal and vertical alignments were formed. The obtained horizontal and vertical alignments were re-formed in an approximation method from tangents and circular curves.

Knowing the parameters of horizontal alignment elements, tangents and horizontal curves the study road sections were assessed according to the methodology created by Lamm [9].

To carry out a general traffic safety analysis of the segment of horizontal alignment all three Safety Criteria were joined into one system – traffic safety module. The following design levels could be distinguished within the module (Table 2):

- good design level – weight coefficient +1, no correction is needed for the segment of horizontal alignment;
- fair design level – weight coefficient 0, engineering traffic safety improvement measures are recommended for the segment of horizontal alignment;
- poor design level – weight coefficient -1, the segment of horizontal alignment must be corrected.

Table 2 – Classification of design levels [9]

Safety Criterion	Design level		
	Good (+)	Fair (0)	Poor (-)
	Permissible differences $\lvert CCR_{Si} - CCR_{Si+1}\rvert \leq$ ≤ 180	Tolerated differences $180 < \lvert CCR_{Si} -$ $- CCR_{Si+1}\rvert \leq 360$	Non-permissible differences $\lvert CCR_{Si} - CCR_{Si+1}\rvert >$ > 360
SC I	$\lvert v_{85i} - v_P\rvert \leq 10$	$10 < \lvert v_{85i} - v_P\rvert \leq 20$	$\lvert v_{85i} - v_P\rvert > 20$
SC II	$\lvert v_{85i} - v_{85i+1}\rvert \leq 10$	$10 < \lvert v_{85i} - v_{85i+1}\rvert \leq 20$	$\lvert v_{85i} - v_{85i+1}\rvert > 20$
SC III	$f_{RA} - f_{RD} \geq 10$	$-0{,}04 < f_{RA} - f_{RD} \leq 0{,}01$	$f_{RA} - f_{RD} < +0{,}01$

Design levels are determined in both driving directions, their arithmetical average is calculated and based on the ranges presented in Table 3 the final assessment is carried out.

Table 3 – Design levels of traffic safety module [9]

Design levels of traffic safety module
$x \geq 0.5$ → Good (+)
$-0.5 < x < 0.5$ → Fair (0)
$x \leq -0.5$ → Poor (-)

4. ANALYSIS AND EVALUATION OF INVESTIGATION RESULTS

The analysis of investigation results indicated that the design level of horizontal alignment elements of low-volume roads according to SC I is fair and sometimes even poor. This shows that the operating speed v_{85} in road elements is 10–20 km/h higher than the design speed v_d (Figure 3).

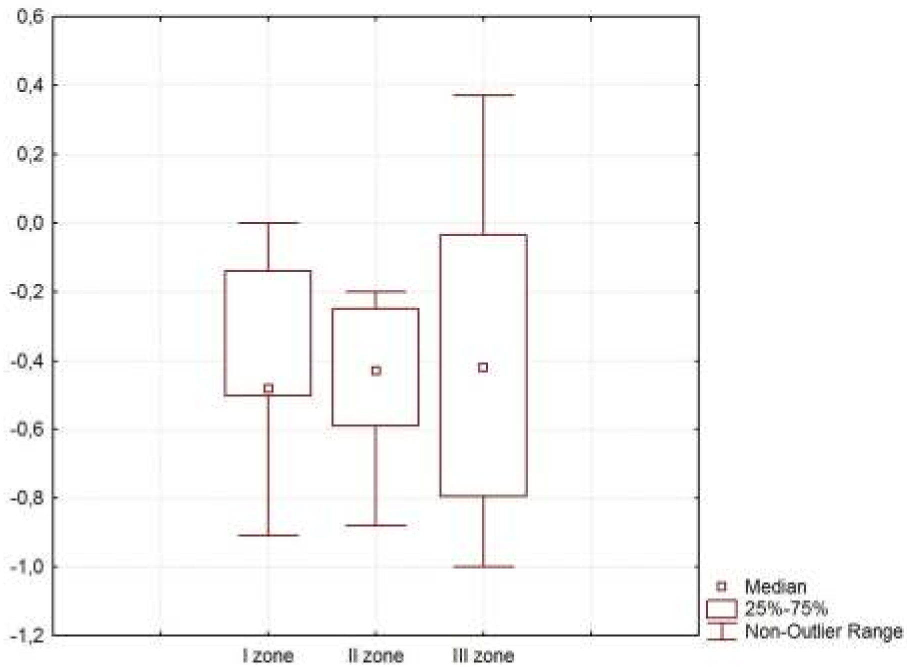

Figure 3 – Dispersion of the research results of the study roads (SC I) by zones

The second Safety Criterion (SC II) assesses the operating speed v_{85} in the successive elements. Design solutions in this aspect are fairly compatible. 10 % of the study roads have the value of SC II lower than 0, the value of SC II of the majority of roads is close to 0.5 (Figure 4). This shows that compatibility of curves and tangents on low-volume roads is fair.

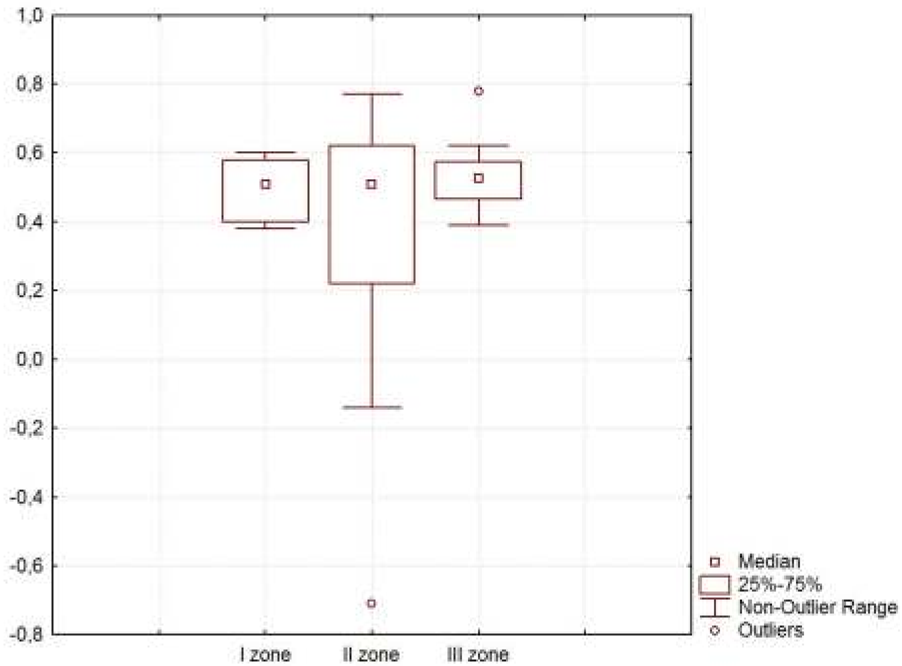

Figure 4 – Dispersion of the research results of the study roads (SC II) by zones

The third Safety Criterion (SC III) assesses dynamic consistency on curves. Figure 5 shows that according to this criterion the dynamic stability of 7 % of roads is poor, 80 % – fair and 13 % – good. Such results could be caused by a wrong size of superelevation on curves due to the fact that the gravel road section was unlevelled or built long ago when there were no requirements to horizontal curves.

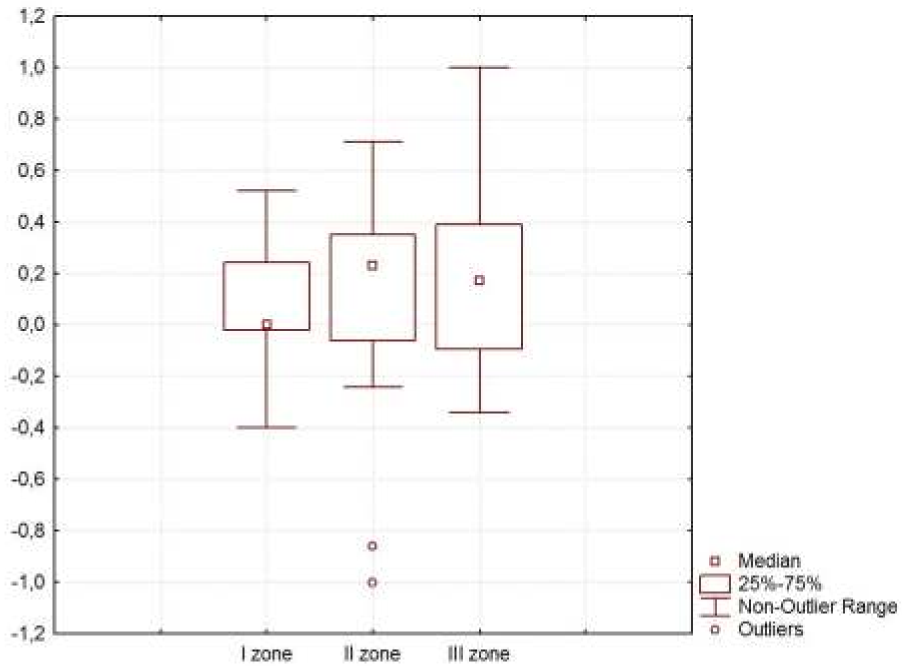

Figure 5 – Dispersion of the research results of the study roads (SC III) by zones

Hypothesis testing results enables to state that Safety Criteria in different zones differ insignificantly, since the available statistical data does not contradict hypotheses about the equality of averages. It could be stated that roads located within three zones are different in their parameters of the elements of horizontal alignment lines due to the specific features of relief of each zone. However, this has no influence on road safety.

For the determination of geometric parameters of the planned road alignment elements, knowing the design speed and the desirable design level of road alignment, the inverse Lamm method can be used for solving the problem according to the above algorithm for identifying the SC I design level.

Low-volume roads correspond to the road categories V and VI where v_d is 70 km/h. When solving minimization problem and having the aim that the design speed v_d would have the least difference from v_{85}, the dependency of v_{85} on R was determined (Figure 6). Figure 6 shows that in order to achieve the most constant as possible driving speed, the curve radius, when the design speed v_d is 70 km/h, must be 106.53 m.

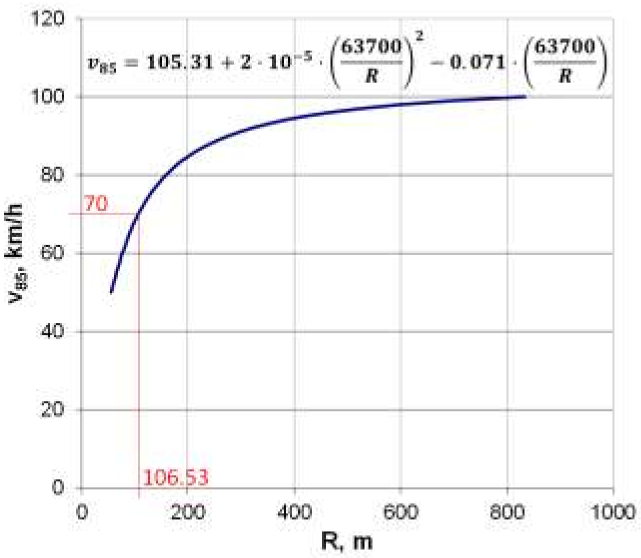

Figure 6 – Dependency of v_{85} on R, the design speed v_d is 70 km/h [11]

When solving the inverse problem of SC II algorithm the dependency of the minimum tangent length TL_{min} on the difference of between the radii of circular curves (R_1–R_2) was searched for. Problem solving was started with a condition that one of the initial radii of curves is 106.53 m, and this is the smallest radius at the design speed. Dependency between the radii of curves and the minimum tangent length is the best described by a monogram (Figure 7). A blue curve shows the dependency of TL_{min} on the difference between the radii of curves when driving at the design speed of 70 km/h, i. e. when the radius of one of the curves is constant – 106.53 m. Other curves show the dependency when the difference between the radii of curves and the radius of one of the curves are known.

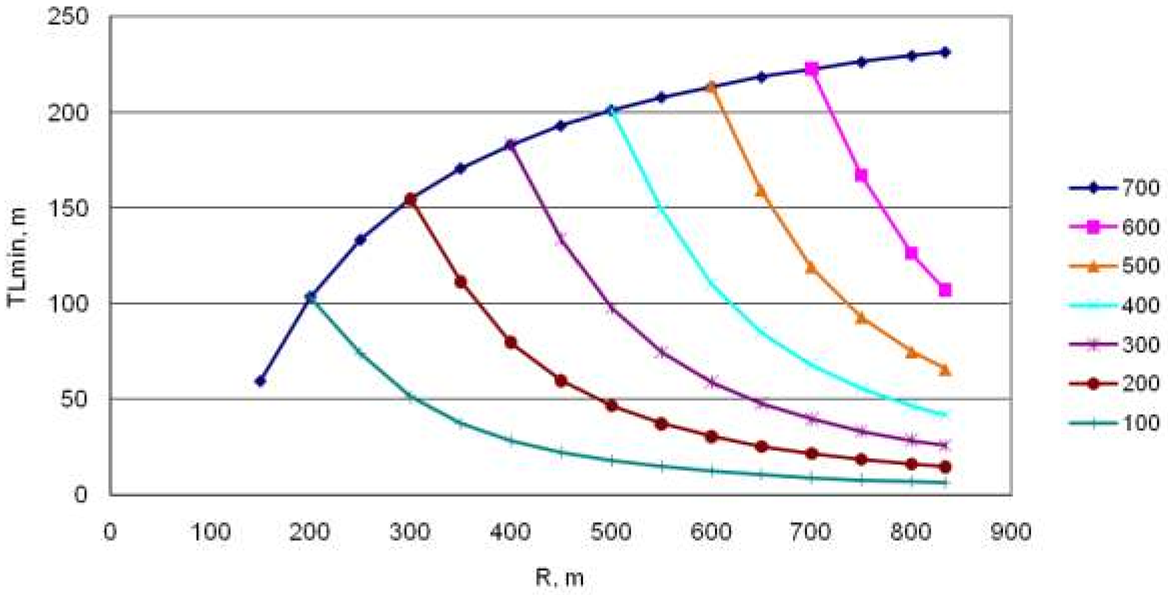

Figure 7 – Dependency of TL_{min} on the difference between R_1 and R_2

Analysis of the algorithm for identifying the SC III design level of the horizontal alignment elements (Figure 8) showed that by assuming initial indices it is possible to determine what the turning radius must be in order to meet the desirable design level conditions. Figure 8 shows that in order to achieve a good design level of an element of horizontal alignment according to SC III, the smallest radius of horizontal curve must be 296.1 m, to achieve a fair design level – at least 230.2 m.

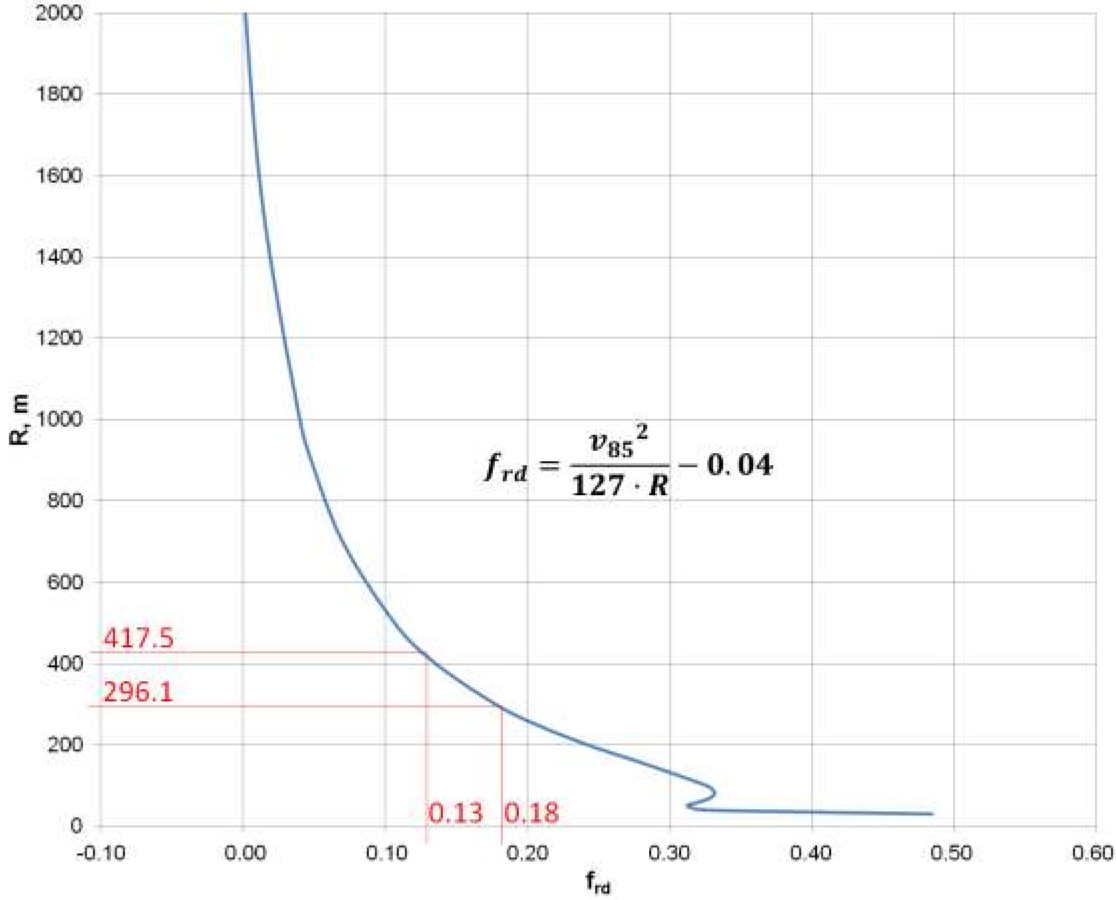

Figure 8 – Dependency of the real transverse force coefficient on the radius of horizontal curve

The assessment of vertical alignment of study roads was carried out. For the assessment purposes the sight distance, the stopping sight distance and the passing sight distance in sag or crest vertical curve were calculated. Investigation results were compared and assessed according to the current requirements to sight distances set in design standards.

According to Road Technical Regulations the sight distance on the regional roads where v_d is 70 km/h shall vary from 80 to 105 m depending on longitudinal gradient. Figure 9 shows that in all cases roads meet the requirements for stopping sight distance. If project speed is 90 km/h the stopping sight distance shall respectively be from 120 to 220 m depending on longitudinal gradient. In this case only about 98.7 % of roads would meet the requirements for stopping sight distance.

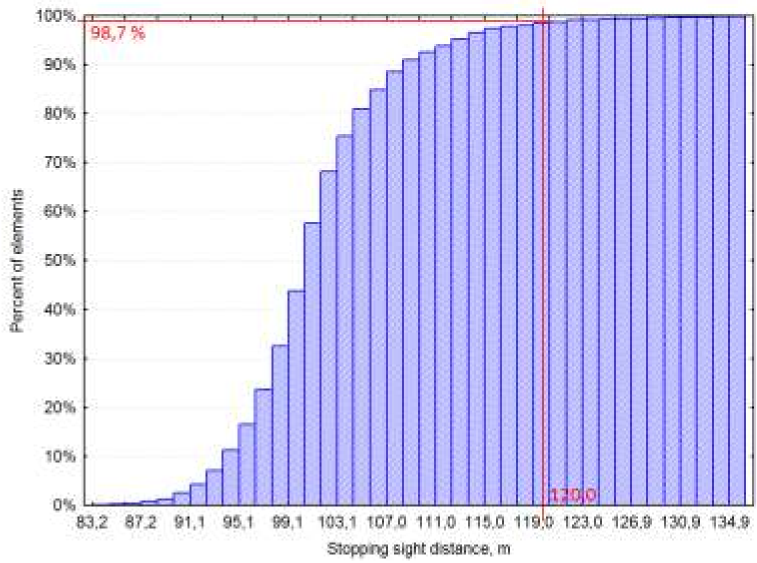

Figure 9 – Empirical distribution function of stopping sight distance

Based on the RTR the passing sight distance on the regional roads shall be at least 450 m where v_d = 70 km/h, and at least 575 m where v_d = 90 km/h. Figure 10 shows that only 8.2 % of study roads meet the requirements for passing sight distance where v_d = 70 km/h, and only 3.8 % of roads would meet the requirements for passing sight distance where v_d = 90 km/h.

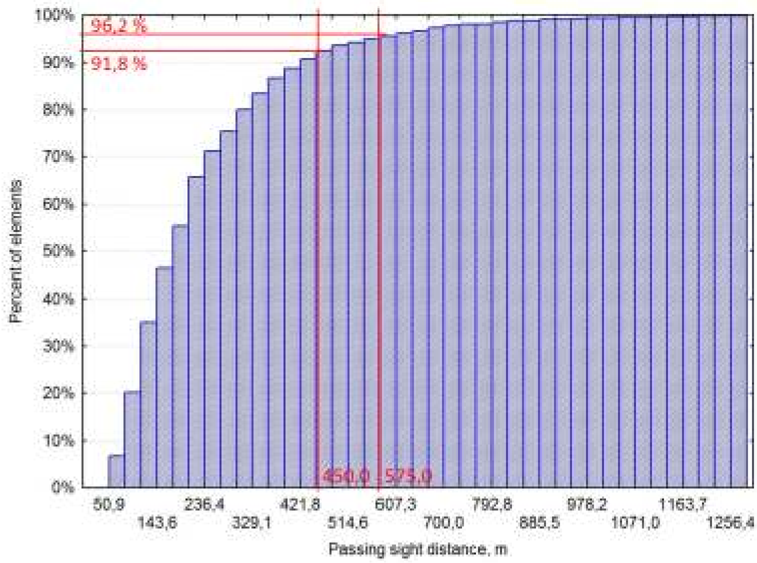

Figure 10 – Empirical distribution function of passing sight distance

The reason for such nonconformity of the passing sight distance to the requirements is the unclear road technical requirement's methodology for determining the passing sight distance. Also, road technical requirements give no methodology for determining the stopping sight distance. The mentioned inaccuracies could cause misunderstandings for designers when assessing the correspondence of the elements of vertical alignment to the sight distance conditions.

CONCLUSIONS

It was determined by the analysis of road classification in Lithuanian that the current road classification procedure prevents from reaching the aim to adapt road to serve only one function. Therefore, it is suggested to supplement the current Road Technical Regulations of Lithuania with a new classification by road function.

The analysis of scientific literature on the assessment of road alignment allows to state that the role of the 85th percentile operating speed is important for selecting parameters of road elements on low-volume roads. Therefore, when designing roads it is recommended to use the 85th percentile operating speed and to supplement the road design standards of Lithuania with this concept of speed.

Analysis of the results obtained by the measurements of horizontal alignment elements of 30 low-volume roads selected for the investigation showed that when assessing correspondence of the horizontal alignment elements to traffic safety the compatibility of elements is very important. When assessing the horizontal alignment elements according to Safety Criteria and preparing reconstruction projects it is essential to assess compatibility of the horizontal alignment elements and their correspondence to traffic safety, since our investigations showed that:

- according to Safety Criterion I the design level of horizontal alignment elements of 33 % of roads is poor and 67 % – fair;
- according to Safety Criterion II the design level of horizontal alignment elements of 3 % of roads is poor, 37 % – fair and 60 % – good;
- according to Safety Criterion III the dynamic consistency on curve of 7 % of roads is poor, 80 % - fair and only 13 % – good.

When assessing the sight conditions in vertical alignment of the study roads it was determined that the passing sight distance on all roads where v_d is 70 km/h meets the requirements, though, if v_d was increased to 90 km/h – the requirements for passing sight distance would be met only by 1.3 % of the study roads. In case of the stopping sight distance it was determined that 8.2 % of roads meet the requirements for stopping sight distance where v_d = 70 km/h. If the design speed v_d was increased to 90 km/h the number of elements meeting the requirements would decrease to 3.8 %. This nonconformity of results is one of the reasons for the minimum correction of horizontal alignment line and for unclear methodology how the sight distance in vertical alignment shall be assessed.

It is suggested to supplement the section of Road Technical Regulations of Lithuania, which defines requirements for the sight distance, with the following:

- to define separate requirements for horizontal and vertical alignment;
- to supplement calculations of vertical alignment with the calculations of stopping sight distance and passing sight distance;
- to define requirements for the minimum sight distance.

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