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LONGITUDINAL PROFILE OF THE OBJECTS INCLUDED IN THE GRAVEL ROADS PAVING PROGRAMME OF LITHUANIA

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Abstract. For the implementation of the Gravel Roads Paving Programme on the Lithuanian roads the reconstruction projects of the existing gravel roads are being prepared. This article studies the problems caused by taking the design solutions and correcting a longitudinal road profile of the objects included in the Gravel Roads Paving Programme. It also gives the results of investigating a longitudinal profile of gravel roads under the supervision of the State Enterprise Telšiai Regional Roads Administration. Based on investigation results, the design radii of vertical curves are suggested and recommended to use in projects for paving gravel roads.

Keywords: gravel road reconstruction, longitudinal profile, vertical curve radius, paving of gravel roads.

1. Introduction

2002–2015 the Road Maintenance and Development Programme of the Republic of Lithuania provides for paving of 2310 km of gravel roads at the full costs of 1,09 billion Litas [1]. The practices of implementing the Gravel Roads Paving Programme shows that it became usual to more or less avoid the correction of road plan and longitudinal profile according to the requirements of a current design code. Motivation is rather different –– starting with the assumption that the construction cost of asphalt concrete pavement becomes unreasonably higher and ending with the discussions on the negative impact on traffic safety due to the increased driving speed on low-volume roads.

A very important stage in the process of building or reconstructing any road is the design of longitudinal profile. Decisions, taken at this stage, are of decisive importance to both the quality of road traffic and the efficiency of investments [2, 3]. It is necessary to ensure a certain sight distance, ie a distance in front of the vehicle which would allow the driver to detect the obstacle, to perceive danger, to overtake the obstacle or to stop before reaching it. Therefore the problems of visibility and visual quality evaluation are studied in road design and are related to traffic safety [4–6].

Based on the theory and practice of road design, many schemes could be suggested for the determination of sight distance, taking into account traffic conditions, distribution of vehicles and obstacles on the road. All these schemes could be divided into two groups:

- the schemes of the stopping sight distance – a road section allowing the driver, to stop before the obstacle detected on the carriageway or before an opposing vehicle;
- the schemes of the overtaking sight distance – a road section allowing the driver to overtake the obstacle detected on the carriageway or to overtake safely the vehicle of the same direction, when going to the opposite traffic lane.

Regulation of Motor Roads STR 2.06.03:2001 [7] requires to guarantee the stopping and overtaking sight distances for the vehicles driving at a design speed v_p (Table 1). The required stopping sight distance according to Regulation of Motor Roads STR 2.06.03:2001 is determined by nomograms, which could be expressed by a following formula:

$$S_s = f(v_p, i), \quad (1)$$

where v_p – design speed, km/h; i – gradient, %.

The overtaking sight distance is in all cases larger than the stopping sight distance. Regulations of Motor Roads STR 2.06.03:2001 indicates that part of the state road sec-

Table 1. Limit values for the sight distance according to the Regulations of Motor Roads STR 2.06.03:2001 [7]

Parameter	Limit value for a design speed, km/h				
	60	80	100	120	140
Maximum gradient, %	8	7	6	5	4
Stopping sight distance, S_s, m	78	140	232	334	
Overtaking sight distance, S_p, m	400	500	650		

tions, suitable for overtaking, shall make not less than 50 %. The sight distance estimation schemes shall take into consideration: eye height of the passenger car driver above the carriageway – 1,0 m; eye height of the heavy vehicle driver above the carriageway – 2,0 m; height of opposing vehicle above the carriageway – 1,0 m; height of obstacle above the carriageway – 0,15 m.

The road maintenance standards set the permissible time-limits for the elimination of pavement defects on the lower-category roads; thus the requirement of the Regulations STR 2.06.03:2001, which guarantee a sight distance for only 0,15 m high obstacle, but not for a carriageway surface, is doubtful.

2. Theoretical background for the vertical curve design

In the refractions of longitudinal profile of roads the designed vertical curves must have a sufficiently large radius. In Lithuania when designing a longitudinal profile, the parabolic curves are used and described by the equation:

$$H = H_v + \frac{L_v^2}{2 \cdot R}, \tag{2}$$

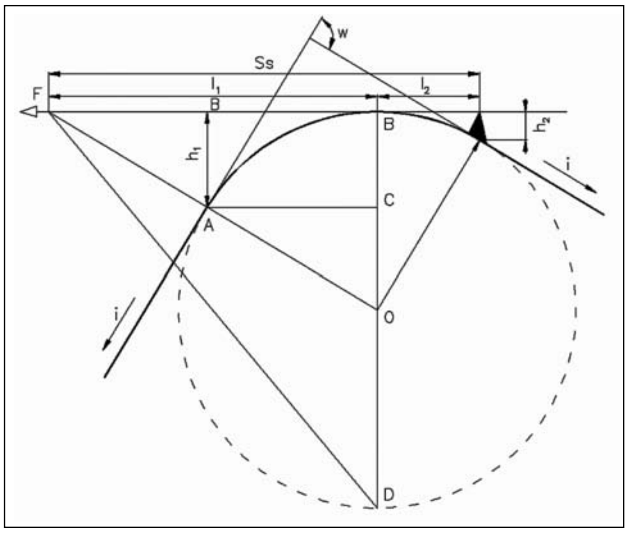

Fig 1. The scheme for estimating the peak vertical curve radius, meeting the assumption on a sufficient sight distance: h_1 – eye height of the driver above the carriageway, m; h_2 – height of the obstacle to be timely detected by the driver, m.

where H – height of a certain point of a vertical curve, m; H_v – height of the crest of a vertical curve, m; L_v – horizontal distance from a certain point to the crest of a vertical curve, m; R – algebraic value of the vertical curve radius, m.

The smallest radius of the peak vertical curves is determined by taking into account a sufficient sight distance of the carriageway or the opposing vehicle [8].

The values of heights h_1 and h_2 are set in the Regulations of Motor Roads STR 2.06.03:2001 [7] (Fig 1). From this scheme the minimum radius of the peak vertical curves can be estimated by the formula:

$$R_{\min} = \frac{S_s^2}{2 \cdot (\sqrt{h_1} + \sqrt{h_2})^2}. \tag{3}$$

When the two opposing vehicles, travelling at the same speed, meet and $h_1 = h_2$, we get the following:

$$R_{\min} = \frac{S_s^2}{8 \cdot h_1}. \tag{4}$$

Meeting the assumption on a sufficient sight distance of a carriageway surface, ie when $h_2 = 0$:

$$R_{\min} = \frac{S_s^2}{2 \cdot h_1}. \tag{5}$$

In formulae (3)–(6), $R_{\min}$ – minimum radius of the peak vertical curve, m; S_s – stopping sight distance, m; h_1 – eye height of the driver above the carriageway, m; h_2 – height of the obstacle to be timely detected by the driver, m.

According to the sight distance of 0,15 m high obstacle, set in the Regulations of Motor Roads STR 2.06.03:2001 ($h_2 = 0{,}15$), the minimum radius of the peak vertical curve is estimated by a formula:

$$R_{\min} = \frac{S_s^2}{2 \cdot (\sqrt{h_1} + \sqrt{0{,}15})^2}. \tag{6}$$

On the sag vertical curve a centrifugal force should be restricted; otherwise, the shock-absorbers of a vehicle could be dangerously overloaded and the driver and the passengers could feel uncomfortably. Centrifugal force acceleration is expressed by an equation:

$$a_0 = \frac{v^2}{R}, \tag{7}$$

where a_0 – centrifugal force acceleration, m/s^2; v – vehicle speed, km/h; R – radius of the sag vertical curve, m.

Therefore the minimum radius of the sag vertical curve should be estimated based on a design speed and the permissible centrifugal force acceleration:

$$R_{\min} = \frac{v_p^2}{a_0}, \tag{8}$$

where $R_{\min}$ – minimum radius of the sag vertical curve, m; v_p – design speed, km/h; a_0 – centrifugal force acceleration, m/s².

A permissible centrifugal force acceleration a_0, meeting the requirements on vehicle overloading and the comfort of the driver and the passengers, should not exceed 0,5–0,7 m/s². When estimating the radius of the sag vertical curve, it is also necessary to take into consideration the fact that in a dark period the vehicle headlamps should illuminate the road surface at a distance not less than a sight distance [9]. Meeting this requirement, the minimum radius of the sag vertical curve can be estimated by an equation:

$$R_{\min} = \frac{S_s^2}{2 \cdot \left(h_l + S_s \cdot \sin\frac{\alpha}{2}\right)}, \tag{9}$$

where S_s – stopping sight distance, m; h_l – height of the vehicle headlamps centre above the carriageway, m; α – scattering angle of the bundle of light rays, spread by the headlamps on a vertical plane, °. According to this expression it is rather difficult to estimate the minimum radius of the sag vertical curve, meeting the requirements for a sufficient night visibility of the road surface. Therefore, in order to simplify this estimation, it is recommended to use the formula (8) with the value of acceleration a_0, not higher than 0,15 m/s².

3. Comparison of the regulated and theoretical vertical curves radii

Theoretical radii of the peak vertical curves were estimated by formulae (4)–(6), assuming that the largest part of the traffic is made by passenger cars, ie it was assumed that $h_1 = 1{,}0$. Since the requirement of the Regulation of Motor Roads STR 2.06.03:2001 on a sight distance of not a carriageway surface but only of 0,15 m high obstacle on a carriageway is doubtful, additional estimations were carried out for a case where $h_2 = 0$. Theoretical radii of the sag vertical curves were estimated by formula (8).

Comparison of the theoretical vertical curves radii with those indicated in the Regulation of Motor Roads STR 2.06.03:2001 is presented in Tables 2, 3 and Figs 2, 3, where:

- STR 2.06.03:2001 (1) – vertical curves radii according to STR 2.06.03:2001, edition 1;
- STR 2.06.03:2001 (2) – vertical curves radii according to the amendment to the STR 2.06.03:2001 of 5 Dec 2002 [10].

When making analysis of Tables 2, 3 and Figs 2, 3, it could be concluded that:

- the minimum radii of the peak vertical curves, indicated in the STR 2.06.03:2001, meet the requirements of the stopping sight distance only in case of a opposing vehicle (where $h_2 = h_1$);
- a sufficient sight distance of 0,15 m high obstacle on the carriageway, according to the radii of the peak vertical curves indicated in the Regulations, is guaranteed only for a design speed of $v_p = 60$ km/h;

Table 2. Theoretical radii of the peak vertical curves

Design speed, km/h	Stopping sight distance, m	Theoretical radius, m		
		$h_2 = h_1$	$h_2 = 0{,}15$	$h_2 = 0$
60	78	761	1581	3042
80	140	2450	5092	9800
100	232	6728	13 983	26 912
120	336	14 112	29 330	56 448

Table 3. Theoretical radii of the sag vertical curves

Design speed, km/h	Theoretical radius, m		
	$a_0 = 0{,}7$	$a_0 = 0{,}5$	$a_0 = 0{,}15$
60	1 429	2 000	6 667
80	2 540	3 556	11 852
100	3 968	5 556	18 519
120	5 714	8 000	26 667
140	7 778	10 889	36 296

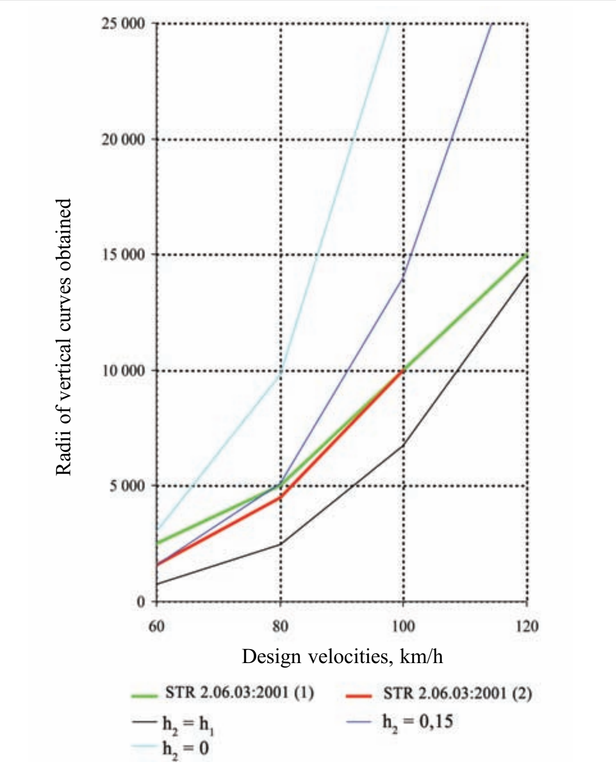

Fig 2. Comparison of the minimum theoretical radii of the peak vertical curves with those indicated in the Regulation of Motor Roads STR 2.06.03:2001

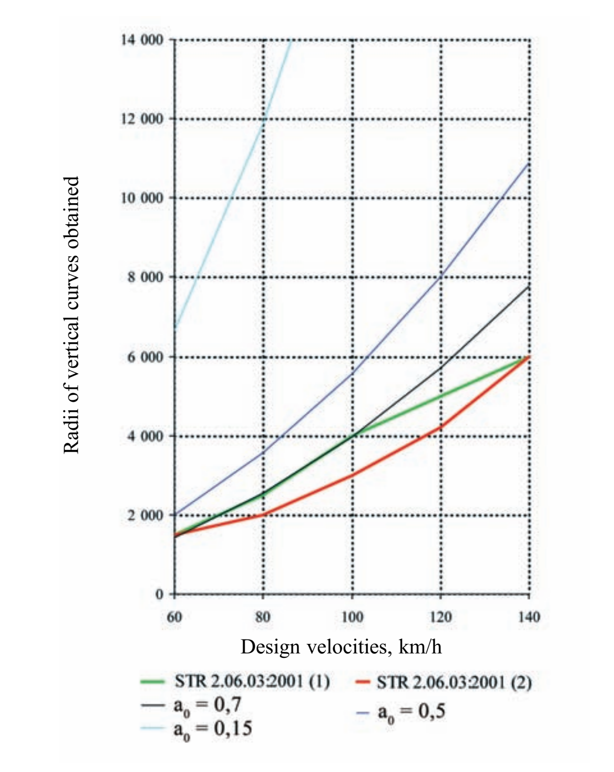

Fig 3. Comparison of the minimum theoretical radii of the sag vertical curves with those indicated in the Regulations of Motor Roads STR 2.06.03:2001

Table 4. The recommended minimum radii of vertical curves [11]

Design speed, km/h	The recommended minimum radii of vertical curves, m	
	peak curves	sag curves
60	2 750	1 500
80	5 000	2 500
100	10 000	5 000
120	20 000	10 000

– to ensure a sufficient sight distance of a carriageway surface, the radii of the peak vertical curves, indicated in the Regulations STR 2.06.03:2001, are too small for all design speeds;
– the minimum radii of the sag vertical curves according to the STR 2.06.03:2001 are too small for almost all estimation cases.

For comparison, the minimum radii of vertical curves, indicated in the Road Design Code RAS-L of the Federal Republic of Germany [11], are given (Table 4).

4. Selection of the gravel road sections study and investigation methodology

Investigation of a longitudinal profile was carried out in the gravel road sections under the supervision of the State Enterprise Telšiai Regional Road Administration. The sections have been included into the list of 2002-–2015 State Road Maintenance and Development Programme of Lithuania [1]. 23 road sections were investigated (total length 107,70 km) (due to an insufficient accuracy 4 investigated sections were rejected (20,60 km) and in 1 section the earlier conducted engineer-geodetical surveying material was used (4,20 km)). In 20 sections, where the measuring accuracy was sufficient (91,30 km), the lists of longitudinal profile elements, corresponding to the existing situation, were drawn up.

In order to make this large-scope investigation as effective as possible, it was decided to use the State LKS 94 coordinate system and the Baltic height system and to apply the GPS (Global Positioning System) technologies for determining the carriageway position and height. The following data storage methods by the GPS devices were used: static, kinematic and RTK (Real Time Kinematic).

For investigating the longitudinal profile of gravel roads the RTK method was selected, the accuracy of which for a horizontal position was: ±10 mm + 0,5 mm/km, for a vertical position: ±20 mm + 1 mm/km. The investigation was performed by the Trimble 5700 GPS and Trimble 5800 GPS devices. A base station of Trimble 5700 GPS was erected at the point with the known coordinates and height. The signals, sent by satellites, were recorded synchronically by a portable receiver (rover) Trimble 5800 GPS, then decoded and stored in a database. The rover was fastened to the vehicle and its height above the carriageway was measured. When driving along the study road sections at 50–60 km/h speed, the satellites signals were recorded every second, ie every 15 m on average three-dimensional coordinates of the carriageway surface were determined within the trajectory of the moving vehicle. Measurement results were corrected by the Trimble Geometics Office software.

A deficiency of the RTK method was noticed – insufficient measuring accuracy was obtained in the sections located in the built-up or wooded areas, with an insufficient number of the seen satellites. For this reason part of the measurements had to be rejected.

In a further stage the task was being solved which could be regarded as the change of a series of three-dimensional points, corresponding to the existing pavement surface, into a series of longitudinal profile elements – straight lines and vertical curves used in the design practice. In other words, for each of the investigated road sections a longitudinal profile was designed with a deviation from the existing position. To solve the task the automated road design system VESTRA CAD was used developed in the Federal Republic of Germany. Using the tools of VESTRA CAD, the task was solved in a following order: development of a Digital Territory Model (DTM), design of road plan; design of a longitudinal profile of the road. Design of a longitudinal profile in VESTRA CAD system was carried out by the vertices method (PVI), ie a design line is set by polygon vertices. For each vertice (PVI) a parabolic vertical curve could be attributed, described by one of these parameters: fixed radius, fixed tangent length, the point to be crossed by a vertical curve. For our investigation a traditional (enabling to reach the maximum efficiency) method of vertical curves description by fixed radii was selected.

For a statistical analysis of the results the VESTRA CAD -– generated reports were used, giving a possibility to present a longitudinal profile in two ways: as a series of elements (straight lines and vertical curves) or as the polygon vertices (PVI) with the selected radii of vertical curves.

5. Analysis and evaluation of investigation results

Based on the created diagram, showing the values of the refractive angles of straight lines of a longitudinal road profile α and the vertical curve radii R (Fig 4), we can state that the random variables α and R can be related in a relationship:

$$R = k \cdot \alpha^n, \tag{10}$$

where k, n – coefficients of exponential function.

A detailed statistical analysis of the refractive angles of straight lines of longitudinal profile and the vertical curve radii on the study road sections was performed by the STATGRAPHICS software (Figs 5, 6). Investigation showed that in those locations where a longitudinal profile had only a slight change there were no vertical curves or their length was smaller than the distance between 3 adjacent measured points. Therefore, when performing a statistical analysis, it was decided to ignore the refraction points of a longitudinal profile without the clearly seen vertical curves.

Using the standard statistical and graphical procedures of the STATGRAPHICS software, a statistical analysis of one variable was carried out for the random variables α and R and a correlation analysis of these random variables. To establish the relationship of these variables a standard polynomial regression procedure was applied, enabling to relate two variables Y and X:

$$Y = a_0 + a_1 \cdot X^1 + a_2 \cdot X^2 + ... + a_n \cdot X^n. \tag{11}$$

It was determined that for the refractive angles of straight lines of longitudinal profile of gravel roads a lognormal distribution law is valid with a 90 % or higher probability, and that the vertical curves radii R and the refractive angles of straight lines of longitudinal profile α are related by a relationship, which could be described by the 7th order polynomial:

$$R = 25\,235 - 26\,346 \cdot \alpha^1 + 12\,444 \cdot \alpha^2 - 3134 \cdot \alpha^3 + 446{,}4 \cdot \alpha^4 - 35{,}9 \cdot \alpha^5 + 1{,}51 \cdot \alpha^6 - 0{,}026 \cdot \alpha^7. \tag{12}$$

Polynomial coefficients, determined during the investigation, can be insufficiently accurate, since we did not succeed to determine the law of the vertical curves distribution radii. The most probable cause of inaccuracy is the

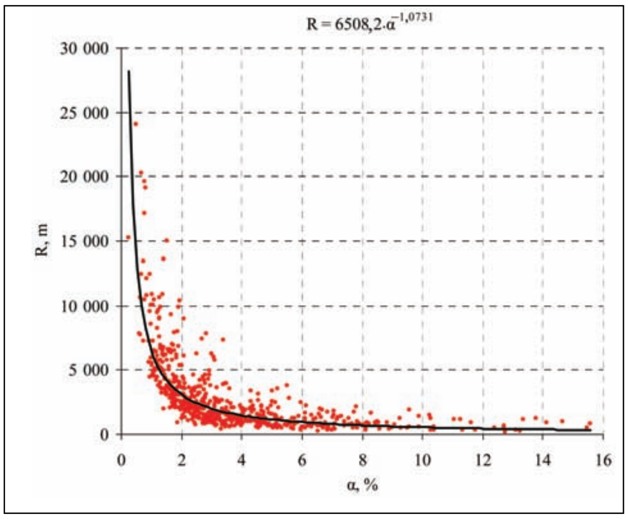

Fig 4. Relationship between the refractive angles of straight lines of longitudinal road profile α and the vertical curve radii R

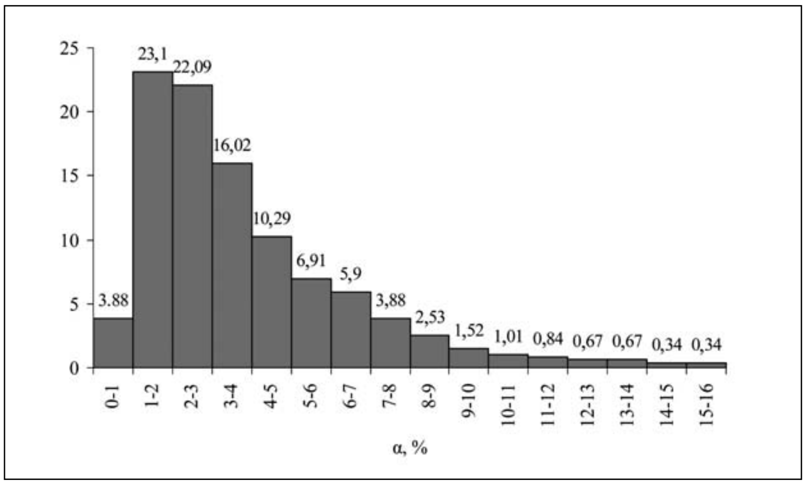

Fig 5. Relative frequency histogram of the refractive angles of straight lines of a longitudinal profile α

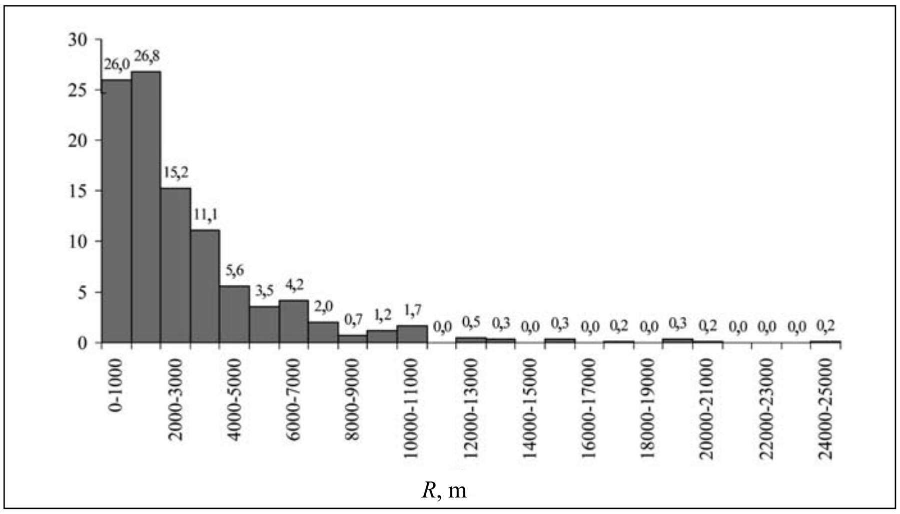

Fig 6. Relative frequency histogram of the vertical curves radii *R*

description of the vertical curves by the fixed radii, ie analytically. The curves radii were set in integral numbers, in the multiples 10, 100, 1000, etc. This method allows the accurate description of each vertical curve, if taken separately; however, it is quite probable that when determining the law of the curves radii distribution, errors are obtained.

Hypotheses of the law in the distribution of random variables α and R were tested by the chi-square test and Kolmogorov methods. It was determined that in the gravel road sections under the supervision of the State Enterprise Telšiai Regional Road Administration:

- the peak vertical curves with the radii less than the permissible ones for a design speed $v_p = 60$ km/h make on average 20,3 % of the total peak vertical curves or 7,8 % of the sections total length;
- the peak vertical curves with the radii less than the permissible ones for a design speed $v_p = 80$ km/h make on average 37,6 % of the total peak vertical curves or 16,0 % of the sections total length;
- the sag vertical curves with the radii less than the permissible ones for a design speed $v_p = 60$ km/h make on average 18,1 % of the total sag vertical curves or 8,2 % of the sections total length;
- the sag vertical curves with the radii less than the permissible ones for a design speed $v_p = 80$ km/h make on average 23,4 % of the total sag vertical curves or 11,7 % of the sections total length.

All the vertical curves with the radii less than the permissible ones for the selected design speed are subjected to corrections. For the design speed $v_p = 80$ km/h, if compared to the design speed $v_p = 60$ km/h, the length of sections with the vertical curves to be corrected increases: on peak curves – 7,8–16,0 % of the total length of sections (by 2,1 times), on the sag curves – 8,2–11,7 % of the total length of sections (by 1,4 times).

6. Conclusions and recommendations

1. When comparing the minimum theoretical radii of the vertical curves with those indicated in the Regulations of Motor Roads STR 2.06.03:2001, it could be concluded:

- the minimum radii of the peak vertical curves, indicated in STR 2.06.03:2001, meet the requirements for the stopping sight distance only in case of an opposing vehicle (where $h_2 = h_1$);
- a sufficient sight distance of 0,15 m high obstacle on the carriageway, according to the radii of the peak vertical curves indicated in the Regulations, is guaranteed only for a design speed of $v_p = 60$ km/h;
- to ensure a sufficient sight distance of a carriageway surface the radii of the peak vertical curves, indicated in the Regulations STR 2.06.03:2001, are too small for all design speeds;
- the minimum radii of the sag vertical curves according to the STR 2.06.03:2001 are too small for almost all estimation cases.

Because the minimum theoretical radii of the vertical curves, indicated in the Regulations, in many cases are smaller than the theoretical ones, it is recommended to revise Chapter IX "Longitudinal road profile" of the Regulations.

It could be recommended to indicate the minimum radii of the vertical curves according to the Road Design Code RAS-L of the Federal Republic of Germany [11].

2. Statistical analysis of the refractive angles of straight lines of longitudinal profile and the vertical curves radii of the study gravel road sections allows to state that for the refractive angles of straight lines of longitudinal profile of

gravel roads a lognormal distribution law is valid, and the vertical curves radii *R* and the refractive angles of straight lines of longitudinal profile α are related by a relationship, which is described by the 7th order polynomial.

3. When laying an asphalt concrete pavement on the gravel road sections, supervised by the State Enterprise Telšiai Regional Road Administration and included into the list of 2002–2015 State Road Maintenance and Development Programme of the Republic of Lithuania, it is recommended to correct their longitudinal profile according to the requirements of STR 2.06.03:2001 for the design speed $v_p = 60$ km/h.

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